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COMPARATIVE STUDY AND DESIGN PROCEDURE,

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SUMMARY

A survey of available wind shear data was conducted and the results were related to current design practices for vertically rising missiles. ~~In addition, a~~ the responses of several different kinds of vehicles were obtained by means of a 6-dimensional trajectory computer program.

The maximum wind velocity and the integrated area under the wind profile (up to the critical altitude at which the maximum wind velocity occurs) were found to be critical parameters. A design procedure was developed for the construction of a design response diagram. This relates the vehicle response to the maximum wind velocity, its probability distribution, and the probability distribution of the integrated area. Since no statistics in the integrated area are available, a method of estimation was also developed, involving the use of four design wind profiles ~~(Appendix A)~~. These design diagrams are useful during all phases of design, as well as pre-launch checkout.

A detailed discussion is presented of the probability concepts involved showing that, in most cases, the probability of occurrence can only be defined by "much less than" a certain percentage.

Several recommendations for future study are made. These include reduction of wind sounding data to obtain integrated area statistics and further refinements in the design procedure for winds aloft.

The proposed procedure has a high degree of flexibility which permits optimization of the design of a missile system. As a result the launch probability can be optimized with respect to the mission of the vehicle and the structural weight traded off against payload capability or flight performance.

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SECTION 1
INTRODUCTION

It is widely recognized that wind shear and gust are important and often decisive criteria in the design of missile systems. This unanimity is lacking, however, when an answer is sought to the question: "What constitutes adequate and sufficient criteria for wind shear and gust in missile design." General agreement is that such criteria must have a probabilistic basis but the interpretation of incomplete statistical data is the cause for much diversity of opinion. Principal sources of this confusion are listed below:

a. The extreme variability of atmospheric winds
b. The lack of statistically adequate data, not only for the American continent but, to a lesser extent, also for specific locations
c. The poor reliability of much of the data collected to date, principally due to instrument errors (Refs. 1 and 2)
d. The various means employed to reduce the raw data obtained by soundings (Refs. 2 and 3)

The generally accepted procedure for evaluating wind-induced structural loads is to approximate the extreme vehicle response using wind profiles of given estimated probabilities. A wind profile is a graph of wind velocity as a function of altitude, where wind velocity is defined by the method used for the analysis of wind sounding data. The earliest procedure was to analyze the radiosonde data statistically for horizontal wind velocity only. The resulting profiles depict average wind velocities and average-plus-n-number-standard-deviations extreme winds, (Fig. 1). This process smoothes out the wind shears and, since shears are critical for vertically rising vehicles, it destroys the usefulness of the data for missile design. The more recent approach is to compute the shears for each sounding and then evaluate the shears statistically (Refs. 1 and 2). Since only shears are obtained, the profiles need to be rounded out with velocity statistics obtained by the former procedure (Refs. 7 and 8).

Several factors have led to the general acceptance of wind profiles for engineering application:

a. Maximum wind velocity and shear generally occur in the altitude interval of 30,000 to 45,000 feet, the same region where critical flight conditions usually occur.

b. Wind direction remains fairly constant with altitude when the wind velocity is well above average (Ref. 8).

c. Strong wind velocities and strong vertical wind shears are associated with each other, at least in the levels of maximum wind velocity in the upper troposphere (Refs. 1 and 8).

d. Determination of the vehicle response to a wind profile input is rather straightforward and the effects of gust and elastic body modes may be obtained by superposition.

e. Sufficient radiosonde data are available for determining wind velocities and shears at various confidence levels with a reasonable degree of reliability.

With the selection of the procedure utilizing wind profiles, it remains to determine specific design profiles for different levels of probability. Inspection of the wide variety of one percent wind profiles published in the literature (Refs. 1, 7, 8, 9, 10, 11, 12, 13, 14) shows that there is general agreement that:

a. Maximum wind velocity and shear should coincide;

b. Maximum wind velocity generally occurs in the altitude interval between 30,000 to 45,000 feet.

c. The vehicle should be analyzed for wind shear at least at the most critical altitude within the above interval.

In addition, reasonably close agreement exists on the magnitudes of the maximum wind velocity and shear. On the other hand, areas of disagreement are:

a. Should a gust be superimposed upon the shear and if so, what should be the gust velocity and gust length.

b. How does the wind velocity vary for altitudes below and above the shears.

c. Should the design wind profile incorporate zero ground wind or statistical ground wind.

Since the objective of this study is the development of wind criteria for vertically rising vehicles and not the general investigation of atmospheric winds, the determination of a design procedure was made dependent upon the response of several current missiles to a variety of wind profiles. A study of critical response features then led to the selection of the principal parameters and the formulation of an overall design procedure.

SECTION 2
WIND VELOCITY DATA

Although atmospheric soundings have been made for many years, the data usually are used for meteorological purposes for which they were originally intended. It was not until 1954 that Norman Sissenwine (Ref. 7) made a first attempt at defining a one percent wind profile for use in missile design (Fig. 3, profile No. 1). This profile was derived from sounding data available at that time, with particular emphasis on the North-Eastern United States, considered the windiest part of the continent. The approach was to define, from wind statistics, the maximum wind velocity (300 fps) and associated maximum shear (45 fps/1000 ft = 0.045 sec^{-1}) likely to be exceeded only one percent of the time during the winter season. The remainder of the profile, above and below the shear at 35,000 ft were developed using ratios of the wind velocities of the limited number soundings where the wind velocity approached 300 fps at 35,000 ft altitude.

In a subsequent study (Ref. 8), Sissenwine developed wind profiles for Patrick AFB at various probabilities of exceedance. The approach is very nearly the same as that of Ref. 7 with the exception that the study is essentially limited to Patrick AFB sounding data. The results are four profiles at 1, 5, 10, and 20 percent calculated risk during the winter time. The one percent profile (Fig. 3, profile No. 2) has a maximum wind velocity of 298 fps at 45,400 ft altitude, accompanied by a shear of 0.046 sec^{-1} and shear lengths of 1000 ft below and 3000 ft above the peak. The remainer of the profiles consists of actual sounding data chosen to correspond closely with the maximum wind velocities and shears.

The foregoing studies, as well as one conducted by Tolefson (Ref. 2), are all based on data collected with AN/GMD-1 sounding equipment. This instrument produces considerable inaccuracies in wind velocity measurements especially at high altitudes and for strong wind velocities, resulting in gross inaccuracies of the computed wind shears. Detailed error studies reported in Refs. 1 and 2 show that the RMS error is often of the same order of magnitude as typical strong shears. In Refs. 7 and 8, Sissenwine attempted to account for these errors while Tolefson in Ref. 2 did not correct for them in the shears presented. Consequently, the Sissenwine method tended to reduce extreme shears of low probability and Tolefson tended to magnify these values.

With the development of the AN/GMD-2 remitter rawin system, instrument errors were reduced by about one order of magnitude (Ref. 1). Therefore, initial measurements with this system reported in Ref. 1 are extremely significant, even though the sample is small by statistical standards. It was found that wind shear and shear length are related, high shears being associated with thin shear layers. For example, the one percent maximum shear is 0.076 sec^{-1} for 1000 ft shear length and 0.050 sec^{-1} for 3000 ft shear length. An important feature of these data is that the correlation of the probability to exceed maximum wind velocity and shear for various shear lengths is shown. The results are summarized in Table 1 and plotted in Fig. 2.

Many other attempts have been made toward the definition of design wind profiles. Lockheed devised a one percent profile (Ref. 9) consisting of statistical minimum wind velocity with a transition to maximum wind velocity of 300 fps in the altitude interval of 30,000 to 40,000 feet (Fig. 4). The transition is a combination of a 0.050 sec^{-1} wind shear over 2000 feet and a 50 fps gust with 500 feet gust length. Convair (Ref. 11) constructed the profile shown in Fig. 4 and Sissenwine (Ref. 12) revised his profile as illustrated in Fig. 3 (profile No. 3), in accordance with the conclusions reached in Ref. 1.

AviDyne Research conducted extensive studies on the missile response to wind shears under contract AF 33(616)-5960 with WADD (Refs. 6 and 10).

A statistical sample was compiled consisting of 279 actual wind soundings considered representative of the seven winters from which it was derived. A missile was "flown" (on the computer) through each one of these profiles to obtain bending moments at three missile stations. Bending moments on the missile at the same three stations were obtained by subjecting the vehicle to synthetic profiles and statistical arrays. The Lockheed profile appeared to yield the best results. The profile recommended for design in Refs. 6 and 10 is so close to that of Lockheed (Fig. 4) that it is not plotted.

Subsequent studies by AviDyne Research (Ref. 13) resulted in the recommended profiles shown in Fig. 5. The disadvantage of these profiles is that they apply only to one percent probability, leaving the designer no room to adjust the profile to the particular mission requirements and the possible limitations of an available booster.

A summary of the major characteristics of the wind profiles discussed in this chapter, including profiles received most recently from Marshall Space Flight Center (Fig. 6), is presented in Table 2.

SECTION 3
VEHICLE RESPONSE

From the foregoing it is apparent that the selection of a satisfactory critical design wind profile is hard to accomplish if the problem is approached from the sounding data only. Reasonably good agreement exists on the maximum wind velocity and shear but the path from ground to shear altitude is subject to wide speculation. The confusion is compounded by the preferences of the various monitoring agencies: The Department of Defense (Ref. 15) specifies the use of the wind profile of Ref. 8 (Fig. 3); WADD (Ref. 10) recommends a profile nearly identical to that of Ref. 9 (Fig. 4); Aerospace Corporation has a preference for the profile of Ref. 13 (Fig. 5); while NASA appears to have most confidence in the data compiled by its Marshall Space Flight Center (Ref. 14, Fig. 6).

Actually, the maximum response of a vehicle is the result of the effects of the wind profile beneath the altitude of maximum shear. The position of the vehicle at maximum shear is dependent upon its response at lower altitudes. Therefore, the only way in which the aerospace industry can work itself out of the wind profile dilemma appears to be the study of the response of different vehicles to the various profiles.

The response to the data presented in Section 2 was obtained by means of an IBM 7090 6-degree of freedom trajectory computer program which incorporated the characteristics of an existing missile (Missile A). The analysis is limited to rigid body effects since winds capable of being measured with present radiosonde equipment do not appear to excite flexible body modes (Ref. 6). The results are summarized in Table 3 and typical response curves are shown in Fig. 7. The analyses were conducted for three wind directions (head, side, and tail), disregarding the structural and performance capabilities of the missile. In some head wind cases this necessitated the removal of the engine stops* from the program. Some conclusions are obvious;

a. The profiles of Refs. 9 and 12 (Lockheed and Sissenwine respectively) are nearly as severe with the Lockheed profile causing the highest response.

b. Although ground winds vary from zero to 35 fps, their effect on the maximum response is not immediately apparent. High ground winds, however, appear to excite a long period mode and may be useful for the evaluation of damping characteristics of the vehicle.

PARAMETER STUDY

To isolate the principle parameters relating wind shear and vehicle response, extensive parameter studies were conducted. To properly describe the response, the parameters αq and βq were determined to be definitive. These parameters correlate closely with the maximum bending moments in the missile structure and since, for the wind directions analyzed, one is negligible when the other is critical, the correlation is with resultant bending moments. It evolves that the response to each wind profile is defined by one value of these parameters regardless whether the α or β response has one maximum, two maxima, or low long period damping.

In the search for a definitive wind profile parameter, numerous variables were investigated. As noted above, the effect of ground wind is not obvious at this stage. There is no direct relationship between wind shear and vehicle response. Shear length affects the response somewhat but not in a consistent manner. The wind velocity increment during shear is related to the vehicle response but the effect is not conclusive enough. Inconsistencies in this plot all had in common that this variable does not involve the effects of the wind profile beneath the altitude of maximum shear. At this point, logic dictated the next step: The integrated effects of a wind profile can be described by the maximum wind velocity V_{max} in conjunction with the integrated area

$$A = \int_0^{H_{cr}} V dH \quad ft^2/sec$$

* Restraints built into the engine gimbal mechanism which limit the engine deflections to a predetermined maximum value.

under the profile, where H_{cr} is the altitude of maximum wind velocity. All profiles with the same maximum wind velocity (V_{max}) fall on a single curve of maximum response (αq or βq) versus integrated area (A), regardless of the wind direction (Fig. 8). The significance of the area A is underscored even more by the finding that a change in critical wind direction occurs at a specific value of the integrated area. For vehicle A this is 3.4×10^6 ft^2/sec, side wind being critical for larger values of A and head wind for smaller values.

In order to investigate these relationships still further, a variety of synthetic profiles was constructed (Table 4, Fig. 9) and the vehicle "flown" through them on the computer. All these profiles have a maximum wind velocity of 300 fps and were constructed around the one percent shears presented in Table 1:

.075 sec^{-1} with 1000 ft shear length
.050 sec^{-1} with 3000 ft shear length

It is seen that these profiles range widely up to excessively severe. The vehicle response for these profiles is plotted in Fig. 10. Besides the obvious conclusion that the data trend is identical to that of Fig. 8, several other observations can be made:

a. Variations of critical altitude induce response changes which are parallel with or on the conservative side of the general data trend.

b. Increasing ground winds cause a reduced response but also a shift of the curve into the critical direction.

The possibility of establishing a family of curves for a range of ground wind probabilities was investigated. However, this approach was abandoned since the present state-of-the-art is such that combined probabilities for ground wind and high altitude shear cannot be determined with any degree of reliability (Ref. Section 5). In the following, therefore, ground wind (up to the approximate one percent maximum of 35 fps) is considered as a random variable which contributes to the data scatter.

Further investigation showed that a response envelope may be obtained in parts, one for each wind direction. All side wind data, both critical and non-critical, plot as an approximate straight line and the same holds for all head wind data. Consequently, regression analyses were performed on both sets of data with results as shown in Figs. 11 and 12. The high value of the correlation coefficient ($r = 0.980$) is mathematical evidence of the excellent linearity of the data ($r = 1$ for perfect linear fit). The scatter of the data about the mean regression line is expressed by the standard error and is suitably small (S_y = 206 and 306 deg-psf respectively). Approximate confidence limits at one-standard error-true confidence limits are hyperbolic - contains the data with only a few exceptions. A composite of the head and side wind regressions is presented in Fig. 13. In order to obtain an envelope of the data, the confidence interval for the head wind data is taken as 1.41 standard errors. It is seen that only the response of profile S21 exceeds the envelope. The probability of conditions represented by this profile ever occurring (Fig. 9) is so remote that it will be disregarded. The linear components of the response envelope intercept at $A = 3.385 \times 10^6$ ft^2/sec which is in excellent agreement with a previous observation based upon the individual data.

DESIGN PROFILES

The foregoing procedure for obtaining a response envelope is entirely too complex and laborious to be used in the design and launch control of missile systems. Instead, the statistical envelope should be approximated by a minimum number of simple profiles. Inspection of Figs. 11, 12, and 13 indicates that out of all the wind profiles studied, there are four that are definitive (See also Section V). These are (Ref. Tables 2 and 4):

a. The revised Sissenwine profile (No. 3) which is based entirely upon the one percent AN/GMD-2 data of Ref. 1 (Table 1). This profile is constructed with 1000, 3000, and 5000 ft shears (0.075, 0.050, and 0.033 sec^{-1} respectively) that are associated with a maximum wind velocity of 300 fps. The critical altitude is 30,000 ft (Fig. 3).

b. Profile No. 3c which is the same as the revised Sissenwine profile (No. 3) except for a critical altitude of 40,000 ft.

c. The minimum area profile D1, 300. This high-intensity shear profile has an integrated area that may well be smaller than is physically attainable and, therefore, results in a response that can hardly be exceeded. The area was minimized by the selection of a low critical altitude (about 30,000 ft) and extension of the 1000 ft shear associated with the maximum wind velocity — 0.075 sec^{-1} for V_{max} = 300 fps (Table 1) — to 3000 ft shear length (Fig. 9).

d. The maximum area profile D2, 300. The area of this profile was maximized by selecting a high critical altitude (about 40,000 ft) and decreasing the wind velocity linearly from maximum to zero ground wind. (Fig. 9.)

The first two profiles (Nos. 3 and 3c) form a pair that is relatively simple and is rationally derived from recent wind shear data (Table 1). However, the area-range of this pair is relatively small and is exceeded by several other literature wind profiles (Fig. 8). In the following they will be treated as design profiles and denoted by D3, 300 and D4, 300 respectively.

The extreme area profiles D1, 300 and D2, 300 are related to the statistical wind data Table 1. They bracket the range of integrated areas that is physically attainable for a specific maximum wind velocity. Since both profiles are already extreme, the effect of a finite ground wind has been purposely ignored.

Since all four design profiles are related to the same statistical wind shear data (Table 1), they may readily be expanded into series (i.e. D1, 300; D1, 250; D1, 225; etc.) with maximum wind velocity as the argument. For instance, design profile D3, 225 is constructed similar to profile D3, 300 except that the shears associated with the maximum wind velocity of 225 fps (Table 1) are used. The detail development of each one of the four series is presented in Appendix A. In order to facilitate the direct utilization of any profile in the series, the coordinates and integrated areas are presented in tabular and graphical form.

EFFECT OF DIFFERENT VEHICLES

The development of a design procedure would be premature at this point since all the data considered so far were associated with only one vehicle (A). In order to obtain the broadest possible base for the design procedure, two other vehicles (B and C) were selected for analysis. The three vehicles A, B, and C are as radically different as is feasible at present. The two additional vehicles were "flown" through the four design profile series, as well as a selected number of the individual wind profiles used before on vehicle A. The results for all three missiles systems are shown in Figs. 14, 15, and 16. It may be seen that the same trends hold for all three vehicles and design profile series D1 through D4 always define the response envelope. This is so because they approximate the extremes and the mode of the statistical distribution of integrated area. Note also that a maximum wind velocity of about 250 fps appears to be optimum; greater maximum wind velocities may be very costly in terms of structural weight without commensurate gains in probability.

SUMMARY OF PARAMETRIC RELATIONSHIPS

Prior to the development of a design procedure, a summary of the various parameters and their relationships is warranted:

a. The basic parameters that define the response to winds aloft of missile systems studied are:

   (1) Maximum wind velocity;

   (2) Integrated area $\int_0^{H_{cr}} V_w \, dH$ where H_{cr} is the altitude at which the maximum wind velocity first occurs.

   This is valid regardless of the missile system and the severity of the wind shears.

b. The maximum response for all conceivable wind profiles having the same maximum wind velocity is a well-defined function of the integrated area. This relationship holds not only when the wind direction is held constant (Figs. 11 and 12), but also when only critical wind directions are considered (Fig. 13).

c. Within statistical limits, the vehicle response decreases with increasing integrated area.

d. Response envelopes (constant maximum wind velocity, critical wind directions, Figs. 13 to 16) exceed the responses associated with all wind profiles (whether obtained from the literature (Table 2) or arbitrarily (Table 4)) by no more than 4.5 percent on the average within a range from 0 to 10 percent.

e. For constant maximum wind velocity there are two critical wind directions, side wind and head wind. Of these, side wind is by far the predominant one. However, it is conceivable that for certain pitch programs tail wind might be a critical direction rather than head wind.

f. Design profiles D1 through D4 define the response envelope for a specific maximum wind velocity. Because they are based upon statistical wind data (Table 1), they are expandable into series with maximum wind velocity as the argument (Appendix A).

g. Design profiles D1 and D2 are extreme area profiles which may be considered as boundary conditions for the area-response function. They result in wedge-type boundaries within which the response envelopes are contained (Figs. 14, 15, and 16).

h. Design profiles D3 and D4 are made up of statistical wind shears based on actual sounding data (Ref. 1). They should result, therefore, in a probably or most likely response. This is verified by the results: the response to profiles D3 and D4 (or 3 and 3c) is centered between the limits whenever they are critical (Figs. 11 through 16).

i. Design profile D2 is more realistic than might appear at first glance: Its correlation throughout with Sissenwine profile No. 2 is striking (Figs. 14 to 16).

SECTION 4
DESIGN PROCEDURE

Within the limits of statistical confidence, the response of a missile system to winds aloft is completely defined by the diagrams of Figures 14 to 16. The diagrams include the response to winds only and the effects of elastic response were not considered based on conclusions reached in Ref. 6. For design purposes, these diagrams are rather complicated and the necessity of always having to know the integrated area makes them laborious. Therefore, a simplified approach would be well worth-while.

DEVELOPMENT

One of the conclusions derived from the response diagrams of Figures 14 to 16 (Section 3, Page 12) is that the possible response is bracketed by design profiles D1 and D2 while the probable response is associated with design – profiles D3 and D4 (see also Section 5). From this it follows that the integrated-area-parameter can be eliminated by plotting the response as a function of maximum wind velocity along the contour of a design profile series. This results in a wedge-shaped "scatter band" with a maximum wind velocity as the independent variable (Figs. 17, 18, and 19). The band is bounded by the response associated with design profiles D1 and D2 while the most likely response associated with design profiles D3 and D4 is centrally located as expected. The significance of this diagram lies in the following:

a. The independent variable, maximum wind velocity, is a direct variable (directly associated with the physical data) rather than a derived variable like the integrated area.

b. The diagram may be directly associated with probability of occurrence by visualizing a probability scale in the third dimension. The bell-shaped curve would have its mode between D3 and D4 and reduce to near-zero at D1 and D2 (Ref. Section 5).

The design response curves of Figs. 17 to 19 do not negate the significance of the integrated area as a definitive parameter. To the contrary, only by virtue of the integrated-area-parameter can it be stated that, for a specific maximum wind velocity and regardless of the wind profile, the missile system response should not exceed D1 and will occur with the greatest likelihood between D3 and D4 (Ref. Section 5).

The final design diagrams are presented in Figs. 20, 21 and 22. They consist of:

a. The design wind response of Figs. 17 to 19. In most cases there will be no need to include the lower boundary (D2).

b. The probability to exceed the maximum wind velocity as obtained from Table 1. Note that the probability curve is associated only with the most likely response (D3 and D4), never with the envelope (D1). This derives from the observations made about probability of occurrence in (b) above (See also Section 5, Page 22).

c. Any capability limitations of the missile system such as structural, engine gimbal stops, etc.

The design diagram may be put to many uses as shown. For a completed missile system, the launch probability and the safe maximum wind velocity (without detailed analysis of pre-launch wind soundings) may be determined (Fig. 20). In the early stages of design, required limit capabilities may be obtained based upon launch probabilities desired by the customer (Fig. 21). Note that decreasing the probability to launch from say 99% to 95% may result in relatively vast weight savings and that this relationship is nonlinear. For operational missile systems the diagram's usefulness is that it facilitates a pre-launch check whether limit capability may be exceeded (Fig. 22). A detailed trajectory analysis to ascertain of safe launch conditions is required only when the maximum wind velocity obtained from wind soundings is in the grey area where limit capability lies between the most likely and extreme response.

DETAILED PROCEDURE

The actual procedures to be used for a new design will vary with the requirements peculiar to the missile system. Although a more or less complete procedure is outlined, a much more simplified version will be adequate in most instances. For instance, in some cases the design response envelope (D1) may be all that is required. In other cases only one probable response curve may be desired (D3 or D4, whichever is maximum). In order to establish all the curves of the design diagram, the following procedure is most efficient:

a. If applicable, update Table 1 with the latest data from the literature and revise the tables in Appendix A accordingly.

b. Perform a trajectory analysis for the no-wind condition. Study the results and make any changes required in the control and command data.

c. Establish the extreme maximum wind velocity desired (300 fps in this report), construct design profile D1 and perform trajectory analyses using all wind directions and with all capability limitations (i. e., engine stops) removed. Determine the two most critical wind directions and perform all future trajectory analyses with these two only.

d. Construct design profile D1 for two or three intermediate maximum wind velocities and perform trajectory analyses. Start the design diagram with the response envelope and probability curve (from Table 1). In some cases this may be all that is required.

e. Determine whether the probable response is desired for both design profiles D3 and D4 or only the maximum of the two. Determine the critical altitude as required, using the results from previous analyses; if necessary, perform trajectory analyses for the extreme maximum wind velocity at various critical altitudes.

f. Construct design profiles D3 and/or D4 for the extreme maximum wind velocity and two or three intermediate values and perform trajectory analyses. Plot the probable response on the design diagram.

g. If desired, construct design profile D2 using no more than three maximum wind velocities including the extreme one.

h. Complete the design diagram with all capability limitations that may prevail. This includes any limitations that were temporarily removed from the trajectory analysis program.

EFFECT OF WIND DIRECTION

At times, a missile system is specifically intended for launching from one base only. If this is a base with a predominant wind direction such as

Cape Canaveral, weight savings may be effected by accounting for this bias. Rather than to assume the maximum wind velocity to be constant regardless of the wind direction as was the basis for the design procedure presented above, the maximum wind velocity may be varied with the wind direction in accordance with local wind statistics. One way to accomplish this is by approximating the wind velocity at a certain altitude and for the desired probability of occurrence by an ellipse with axes in the North-South and East-West directions. With the launch azimuth known, the maximum head, side, and tail wind may then be scaled off the ellipse. For Cape Canaveral, for instance, this procedure results in approximate maximum wind velocities as follows:

151 fps head wind
183 fps side wind
300 fps tail wind

Considering that head wind and side wind usually are critical, this procedure may result in considerable weight savings. Extreme caution must be exercised, however, since a missile system designed to these limited criteria may not be structurally adequate for any other launch site than the one used as a basis for design.

During pre-launch wind soundings, it has sometimes happened that the maximum wind velocity at altitude was moderate but its direction changed quite drastically. This is probably due to two layers of air moving into different directions. In such a case, the missile system response should be greater than that estimated from the measured maximum wind velocity using the design diagram (Fig. 22). How to account for this possibility should be the subject of a future investigation.

PRE-LAUNCH CHECKOUT PROCEDURE

The procedure developed in this report is eminently suited to facilitate prelaunch checkout. It can be used at the launch site rather than at some faraway control center. The only requirement is that some facility be available for the progressive integration of the wind velocity data being obtained from radiosonde measurements. The detailed procedure would be as follows:

a. For the particular vehicle being launched, two plots should be available. The first one should be of the type shown in Figs. 14 to 16 and the other one like Figs. 20 to 22.

b. From radiosonde measurements, the maximum wind velocity and associated integrated area are obtained. The wind direction should be checked to ensure that there is no drastic change resulting in two high shears.

c. On the first plot (like Figs. 14 to 16), a vertical line is drawn at the integrated area associated with the measured maximum wind velocity. Then an envelope is estimated for the measured maximum wind velocity. The intersect of integrated area and maximum wind velocity envelope is then located with respect to the design profile series, just above D4 for instance. Note that the response is not read from this plot since the maximum wind velocity envelope is only estimated and, therefore, inaccuracies would be compounded.

d. Next, the second plot (like Figs. 20 to 22) is entered with the measured maximum wind velocity and a vertical line drawn into the response band up to the location obtained under (c), just above D4 in this case. The response associated with this point may now be read and structural and control margins computed.

e. The last step should be to estimate the launch-probability associated with the radiosonde data and to compare it with the design probability level. The difference between the two is an additional measure for the degree of safety associated with the particular launch.

The foregoing procedure has actually been used during several recent launches and was cross-checked against 6D trajectory computer runs for the overall wind profile as measured by radiosonde. The correlation to date has been excellent.

Further improvements in this procedure may be obtained in the future when statistics of the integrated area become available. Then the response band will be defined by curves for specific probabilities to exceed, rather than design profile series D1 through D4. As a result, the joint probability of measured maximum wind velocity and associated integrated area may be estimated and the response expressed in terms of probability to exceed. This will provide a more rational basis for the prediction of the expected response during the actual launch.

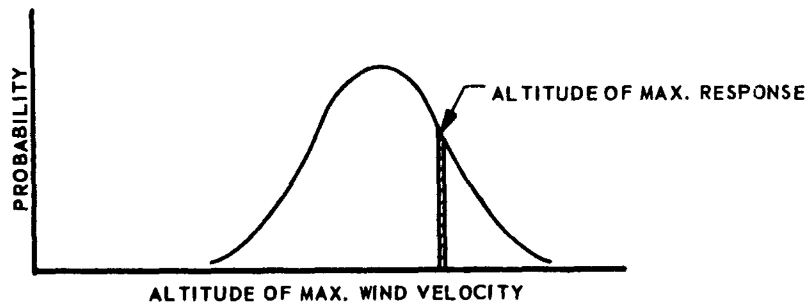
SECTION 5
PROBABILITY CONSIDERATIONS

In the foregoing, relatively little was said about probabilities of occurrence and in the development of the design diagram the probability concept was without further discussion associated with maximum wind velocity only. This was done for purposes of clarity and in the following the various statistical aspects will be discussed in broad terms only.

WIND PROFILES

The general approach to date has been to construct a synthetic wind profile for a certain probability of occurrence using statistical wind sounding data. The result is a large variety of wind profiles (Table 2) which includes responses that vary widely (Fig. 8). The major cause for this wide spread is that the construction of a synthetic wind profile for a specific probability of occurrence is highly subjective and very nearly impossible to accomplish rigorously. Even if it is assumed that all the parameters that define a wind profile individually are accurately defined in terms of probability of occurrence - which they are not - then the probability level of the composite profile is still a matter of conjecture. An example will illustrate this.

The requirement is to define a wind profile with a probability to be exceeded of one percent. Let it be assumed that the AN/GMD-2 data of Table 1 are statistically reliable estimates. Further assume that the one percent ground wind is 35 fps. The composite constitutes the revised Sissenwine profile No. 3 (Table 2) or design profile D3, 300. The average probability for this composite to be exceeded is composed of probability functions associated with the maximum wind velocity, 1000 ft shear, 3000 ft shear, 5000 ft shear, 35 fps gound wind, and critical altitude. While maximum wind velocity and shears individually are one percent values, the probability of these occurring simultaneously is at best 60 percent (Ref. 1), resulting in a joint probability less than one percent. All evidence indicates that winds aloft and ground winds are independent variates (statistical variable), meaning that their probability functions must be multiplied to obtain their joint probability function. The result is an effective probability to exceed vastly less than one percent. Last but not least, the critical altitude at which the maximum wind velocity occurs has its own independent distribution. The probability for the critical altitude to occur specifically at the altitude of maximum response of a certain missile system is always very small (cross-hatched area in sketch). In summary, the probability associated with a composite wind profile can be defined only in terms of "much less than," much less than one percent in the above example.



DESIGN DIAGRAM

Even if highly reliable statistical data were available on all the parameters that enter into the vehicle response to winds aloft, a project to compute the associated probabilities would not be worth-while. The reason is that the result would be average probabilities to exceed which in turn have their own statistical distributions. No matter how great the computational effort, the response for a certain probability level may only be determined within confidence limits. The effect of increasing analysis effort would only be to narrow these confidence limits. Since the physical phenomenon is a random process, rather wide confidence limits are inherent of the data.

With the design procedure developed in Section 4, an attempt has been made to account for this difficulty of statistical definition. The discussion in the preceding paragraphs may also be reversed and the statement made that all the wind profiles presented in the literature (Section 2) are correct in that each one of them constitutes a portion of the overall phenomenon. While most of these profiles are in agreement with regard to the one percent and five percent maximum wind velocities, their shears vary widely as is shown conclusively in Figs. 23 and 24. Nonetheless, their response as a function of integrated area is consistent within rather narrow limits (Figs. 8 and 13). This leads to the inevitable conclusion that the maximum wind velocity is a principal parameter and the effect of the other variables (not including integrated area) is limited to a contribution to the dispersion.

In studying plots like Figs. 13 and 14, two types of dispersion are of concern: (a) of the response about the mean regression curve and (b) the wide spread of the integrated area.

a. Deviations from the mean regression curve are caused by secondary variables such as critical altitude, ground wind, and actual shears. The effect of critical altitude and ground wind have already been discussed (Fig. 10). A study of individual data points (Table 2, Fig. 8) indicates that for constant integrated area low average shears cause a response on the lower side of the confidence band (profile nos. 5a, 5b). However, since the maximum deviation from the envelope is only of the order of 10 percent, refined techniques for the evaluation of the secondary variables do not appear to be worthwhile.

b. Next to maximum wind velocity, the integrated area is the basic parameter which defines the vehicle response. Its range derives from all the different wind profiles which are possible at a constant maximum wind velocity (Fig. 9). These profiles vary randomly, some of them occurring more frequently than others. Therefore, the integrated area has a statistical distribution which is peculiar to the physical phenomenon under investigation. Its distribution may be determined directly from the wind sounding data by simple data reduction methods. Because of its pronounced effect upon the vehicle response, a detailed knowledge of the statistical distribution of this parameter is highly desirable.

Since the statistical distribution of the integrated area is not known at present, its effect must be assessed qualitatively. Referring to Figs. 14 to 16, the probability distribution of the integrated area may be visualized in the third dimension. Along the 300 fps envelope, the probability is near zero at D1, rises to a maximum somewhere around D3 and D4, and drops off to near zero at D2. Similar observations can be made in Figs. 17 to 19.

In summary, the selection of design profiles D3 and D4 to induce the most likely vehicle response is based upon the following considerations:

a. The statistical distribution of the integrated area should have a mode somewhere around D3 and D4.
b. Design profiles D3 and D4 are based upon the most complete statistical wind shears published to date (Ref. 1).
c. The basic design profiles D3, 300 (No. 3) and D4, 300 (No. 3c) are expandable into series which permits the determination of design profiles for any desired maximum wind velocity (Appendix A).

Once the distribution of the integrated area is known, it is possible that a simplified procedure may make the use of the design profiles superfluous. Until such time, however, the design profiles constitute the only means for estimating the mode and limits of the response variation due to integrated area.

The reasons for the format of the design diagram (Figs. 20 to 22) should now be clear. Reasonable reliable statistics are available for the maximum wind velocity and, therefore, are shown. No statistics are available for the integrated area and its effect is estimated with a response envelope (design profiles D1) and a probable response band (design profiles D3 and D4).

In using the design diagrams, it should be borne in mind that the probability to exceed the lower envelope (D2) is about 100-percent, the probability to exceed the mean response (around D3 and D4) is 50 percent, and the probability to exceed the upper envelope is close to zero. Therefore, the joint probabilities at a one percent maximum wind velocity for instance are approximately one percent, 0.5 percent, and zero respectively. It follows that the recommended design procedure to relate probability with the probable response band is conservative.

SECTION 6
CONCLUSIONS AND RECOMMENDATIONS

An elaborate investigation of high altitude winds and their effect upon vertically rising missile systems resulted in the isolation of two definitive parameters, maximum wind velocity and integrated area under the wind profile. Within statistical limits, these two parameters completely define the vehicle response. For constant maximum wind velocity, the response is a monotonously decreasing function of integrated area. All "design" wind profiles recommended in the literature are discrete cases of this general relationship. For the class of missile systems studied, the vehicle response to winds aloft needs to be determined for a rigid body only.

The probability of a certain response to be exceeded depends jointly upon the probability functions of maximum wind velocity and integrated area. For lack of statistics for the integrated area, this joint probability at present must be estimated. This is accomplished with the aid of design profiles described in detail in Appendix A. The specific function of these design profiles is as follows: Design profiles D1 and D2 define response envelopes associated with probabilities to exceed integrated area of approximately zero percent and 100 percent respectively. Design profiles D3 and D4 define the probable response band associated with an estimated mean of the integrated area distribution. Theoretically, the probability to exceed a certain response is the product of the distribution functions of maximum wind velocity and integrated area. This means that for a one percent maximum wind velocity, design profile D2 (lower envelope) induces a response that may be exceeded about one percent of the time, design profiles D3 and D4 (probable response) approximately 0.5 percent of the time, and design profile D1 (upper envelope) close to zero percent of the time. As long as adequate statistical data are not available, however, the conservative approach is recommended to associate maximum wind velocity probabilities with the probable response. In the above example this means that design profiles D3 and D4 are assumed to induce a response that may be exceeded one percent of the time.

The results of this investigation were synthesized in a design diagram (Figs. 20, 21, and 22) which is based upon the parametric relationships and includes the probability considerations discussed above. A detailed procedure for the construction of this diagram has been presented. The design diagram may be used for a variety of purposes during all phases of the design, including a check on the missile system's capability to withstand winds measured prior to launch.

A major advantage of the proposed procedure is its flexibility which permits the designer to trade-off launch-probability against cost in weight and dollars. Unlike with most existing wind criteria, it is now possible to back-off from an initial launch-probability which design analysis may prove to be too high, while retaining a reasonably accurate knowledge of performance gains and the resulting launch probability.

Some miscellaneous conclusions of interest are:

a. The relationship between vehicle response and probability of occurrence is nonlinear. As a consequence, increasing the probability to launch by a few percentage points, say from 95 to 99 percent, will cause the weight to increase disproportionately.

b. If a missile system is being designed for launch from one base only and if this is a base with a predominant wind direction, then significant weight savings may be accomplished by accounting for this bias in the construction of the design diagram.

c. High ground winds may excite a long period mode of the missile system and thus are useful for the evaluation of damping characteristics of the vehicle.

This investigation has resulted in a systematic and parametric approach for the determination of loads due to winds aloft. However, the overall procedure is incomplete, principally for lack of data and, therefore, has purposely been kept conservative. In order to make it possible to obtain more accurate loads and further weight reduction, future studies in the following areas are urgently recommended:

a. The available wind sounding data should be re-evaluated to obtain statistics of the integrated area under the wind profile up to maximum wind velocity at critical altitude. These statistics should be determined as a function of maximum wind velocity. It would be advantageous if the statistical distribution of critical altitude were to be obtained simultaneously.

b. The effect of drastic changes in wind direction upon the vehicle response should be studied and the results incorporated in the design diagram.

For vertically rising missile systems, loads due to gust generally are less severe than wind-induced loads. However, they may still be appreciable and should be considered. Since any gust-load analysis must include flexible body effects, its consideration is beyond the scope of this report. Instead, it will be made the subject of a future investigation.

SECTION 7

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15. Military Specification, Missiles, Guided: Strength and Rigidity Requirements, MIL-M-8856 (ASG), 22 June 1959.

TABLE 1
SUMMARY OF AN/GMD-2 WIND DATA

SOURCE: REF. 1

PROBABILITY TO EXCEED PERCENT	MAXIMUM WIND VELOCITY FPS	SHEAR LENGTH (FT) 1000	3000	5000
		SHEAR, SEC^{-1}		
1	300	0.0760	0.0500	0.0330
2	277	0.0624	0.0406	0.0272
5	250	0.0470	0.0291	0.0215
10	225	0.0369	0.0226	0.0178
20	191	0.0280	0.0181	0.0145
30	170 E	0.0241	0.0156	0.0126
40	150 E	0.0210	0.0137	0.0115
50	130 E	0.0188	0.0121	0.0103
60	110 E	0.0173	0.0108	0.0091
70	88 E	0.0155	0.0096	0.0081

E: EXTRAPOLATED
ALSO SEE FIGURE 2

Table 2
WIND SHEAR SUMMARY

Profile No.	Source	Ref.	Figure No.	Critical Altitude H_{cr} 1000 Ft	Maximum Wind Velocity V_{max} FPS	Ground Wind V_o FPS	Area $\int_0^{H_{cr}} V_w dH$ A 10^6 ft^2/sec	Average: Shear S Sec^{-1}	Average: Shear Length ΔH 1000 Ft	Average: Velocity Increase ΔV_w FPS	Maximum: Shear S Sec^{-1}	Maximum: Shear Length ΔH 1000 Ft	Maximum: Velocity Increase ΔV_w FPS
1	Sissenwine	7	3	35	300	20	4.142	0.045	1	45			
2	Sissenwine	8	3	45.4	298	20	6.010	0.046	1	46			
3	Sissenwine	12	3	30	300	35	2.985	0.050	3	150	0.075	1	75
3a	Sissenwine			30	300	0	2.898	0.050	3	150	0.075	1	75
3b	Sissenwine			40	300	0	3.823	0.050	3	150	0.075	1	75
3c	Sissenwine			40	300	35	3.911	0.050	3	150	0.075	1	75
4	Lockheed	9	4	30	300	0	2.465	0.066	2.35	155	0.200	0.25	50
5	Convair	11	4	30	300	29	4.050	0.045	2	90			
5a	Convair		4	30	300	0	3.923	0.045	2	90			
5b	Convair		4	30	300	0	3.748	0.045	2	90			
5c	Convair		4	30	300	29	3.875	0.045	2	90			
5d	Convair		4	30	300	29	4.398	0.045	2	90			
6	Wadd	10	-	30	310	0	2.466	0.060	2.75	165	0.160	0.25	40
7a	Avidyne	13	5	35	248	10	3.479	0.029	3	87			
7b	Avidyne	13	5	37.5	260	10	3.941	0.028	3	84			
8a	Marshall SFC	14	6	39.372	246	0	2.040	0.037	3	111	0.059	1	59
8b	Marshall SFC	14	6	32.810	246	0	1.897	0.037	3	110	0.062	1	62
8c	Marshall SFC	14	6	32.810	246	0	3.631	0.024	3	72	0.038	1	38
8d	Marshall SFC	14	6	32.810	246	32.8	4.574	0.0065	32.81	213			

Table 3

MAXIMUM RESPONSE FOR VARIOUS WIND PROFILES[1] ~ VEHICLE A

Profile No.[2]	Fig. No.	Tail Wind		Head Wind		Side Wind	
		$-\alpha$ deg	$-\alpha q$ deg - psf	α deg	αq deg - psf	β deg	βq deg - psf
1	3	5.65	4010	4.89	4860	6.71	5720
2	3	4.82	3280	4.39	3730	5.03	3860
3	3	8.75	5720	7.78	7510	8.87	7200
3a				7.77	7490[3]	8.89	7220
3b				5.71	5690	7.29	6220
3c				5.70	5680	7.28	6210
4	4	9.10	5900	7.90	7700	9.34	7610
5	4	7.26	4140	5.27	4920	6.95	5590
5a	4	7.54	4160	5.93	4920	7.04	5660
5b	4	7.00	4380	5.63	5290	7.26	5850
5c	4	6.85	4350	5.59	5250	7.19	5800
5d	4	6.01	4040	5.14	4770	6.84	5510
6	-	9.50	6110	8.32	8170[3]	9.70	7920
7a	5	4.89	3590	4.40	4250	5.72	4860
7b	5	4.53	3340	4.27	4140	5.58	4770
8a	6			5.56	5490[3]	6.88	5870
8b	6			6.45	6320[3]	7.59	6360
8c	6			6.43	4560	6.88	4290
8d	6			3.60	2945	4.29	3550

(1) Disregarding structural capability

(2) Ref. Table 2

(3) Engine stops "removed" to prevent instability

Table 4
SYNTHETIC WIND PROFILES FOR PARAMETER STUDY

V_{max} = 300 FPS

Profile Number	D1, 300	D2, 300	S10	S11	S12	S13	S20	S21	S30	S31	S40
Area x 10^{-6}, Ft^2/Sec	1.575	6.000	2.663	3.068	3.413	3.968	4.500	4.950	3.525	3.960	2.301
1000 Ft Shear, Sec^{-1}	0.075	0.0075	0.075	0.075	0.075	0.075	0.010	0.009	0.075	0.075	0.075
3000 Ft Shear, Sec^{-1}	0.075	0.0075	0.050	0.050	0.050	0.050	0.010	0.009	0.030	0.029	0.0583
Altitude, Ft	Wind Velocity - FPS										
0	0	0	0	30	0	30	0	30	0	30	0
27,000	75		150	150							125
29,000			225	225					225	225	225
30,000	300		300	300			300	300	300	300	300
31,000			225	225					225	225	225
33,000	75		150	150					125	125	125
37,000					150	150					
39,000					225	225					
40,000		300			300	300					
41,000					225	225					
43,000					150	150					
75,000	75	75	75	75	75	75	75	75	75	75	75

Ref. Fig. 9

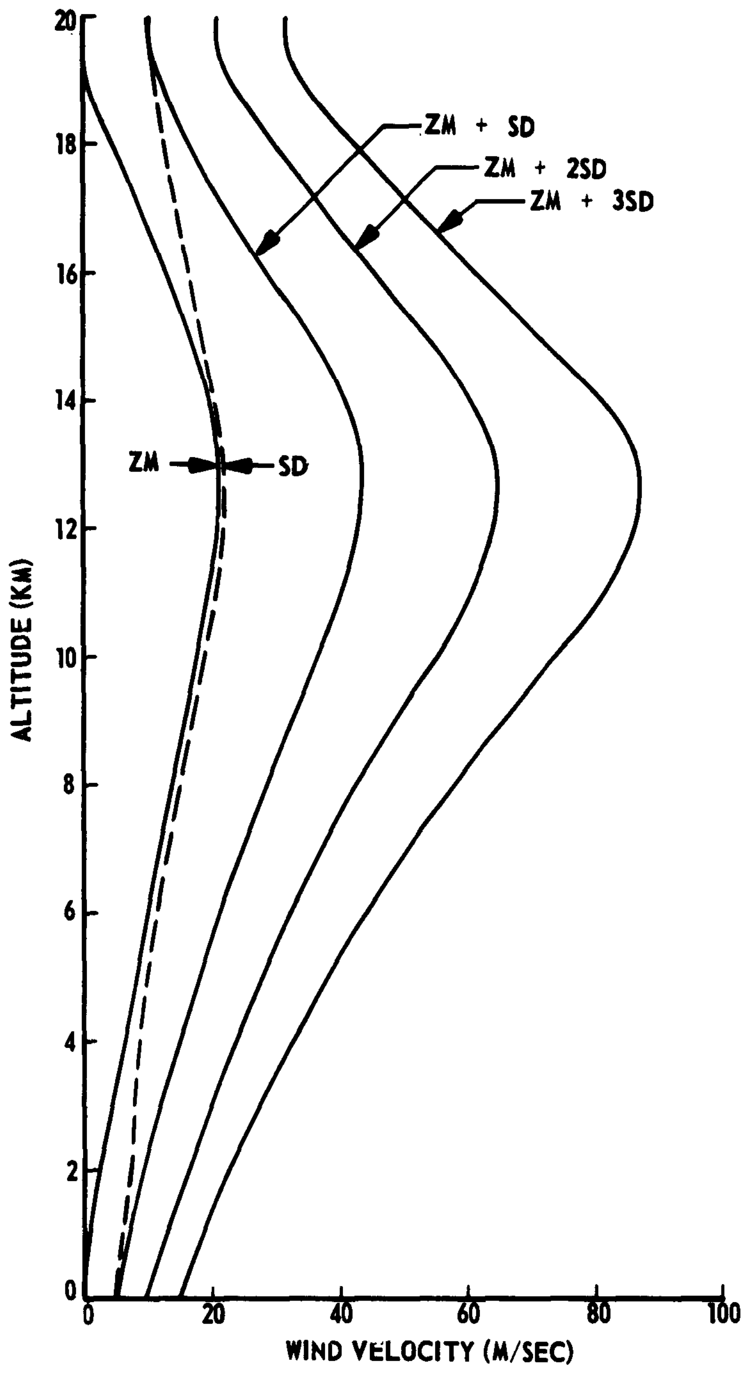


Figure 1 Annual Winds At Patrick AFB

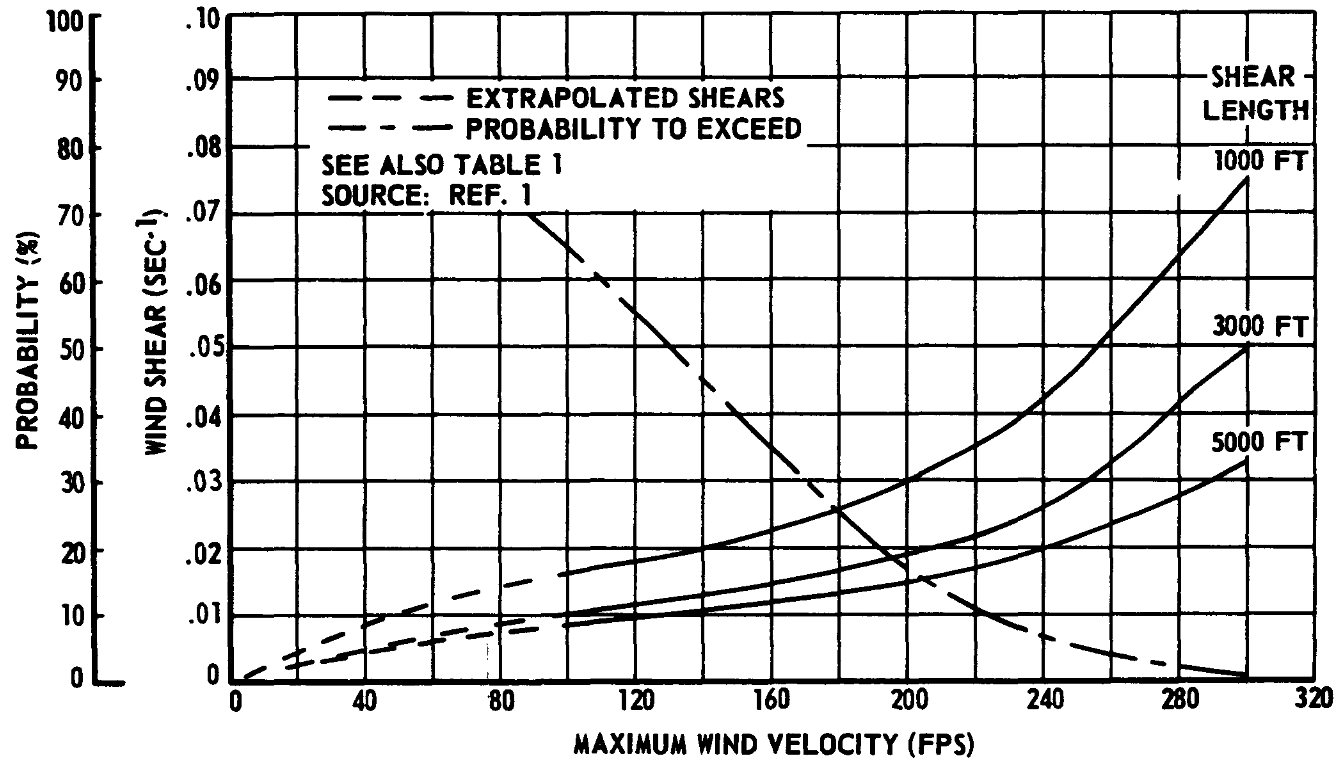


Figure 2 Summary Of AN/GMD-2 Wind Data

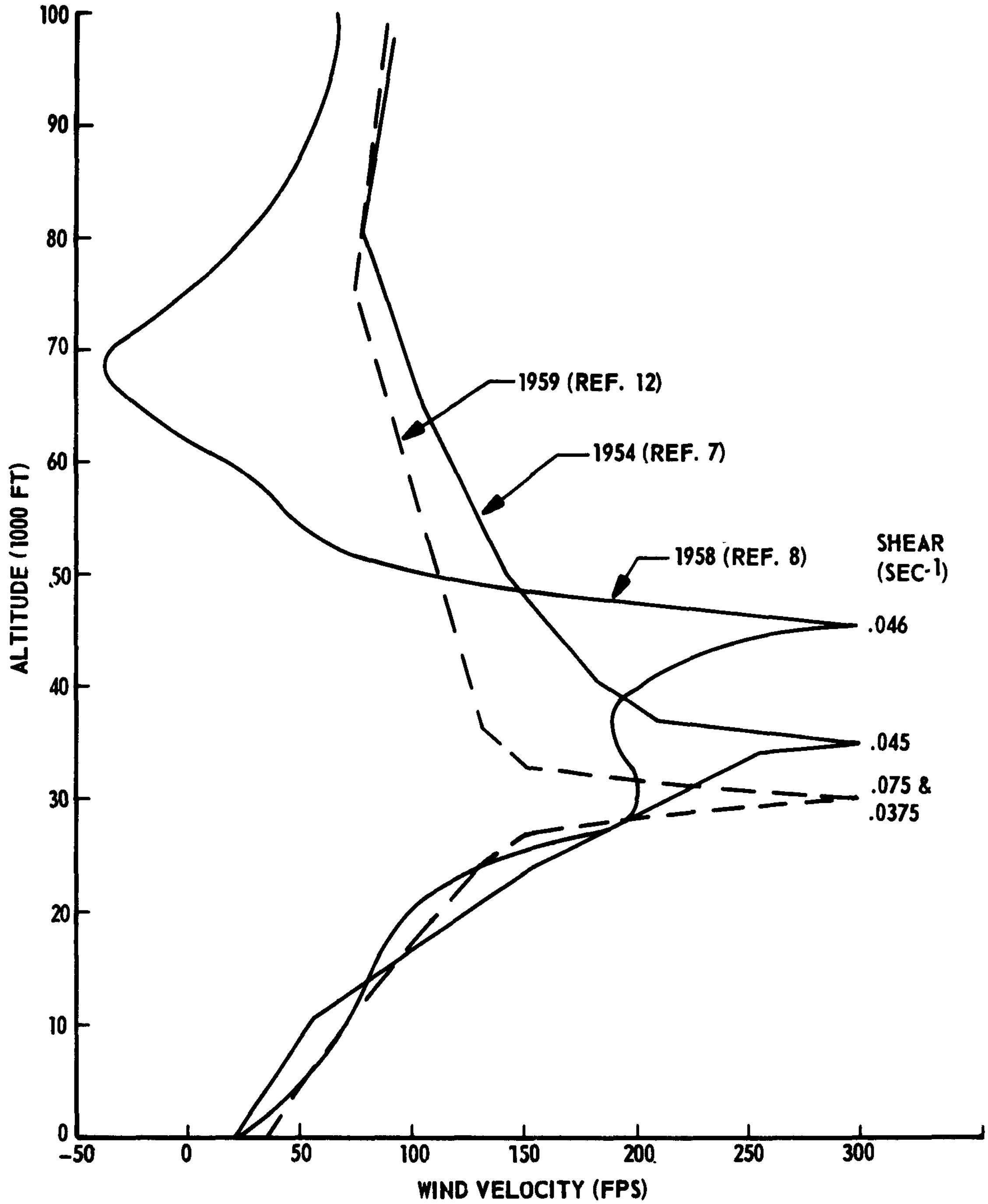


Figure 3 Sissenwine Wind Profiles For 1% Probability During Winter

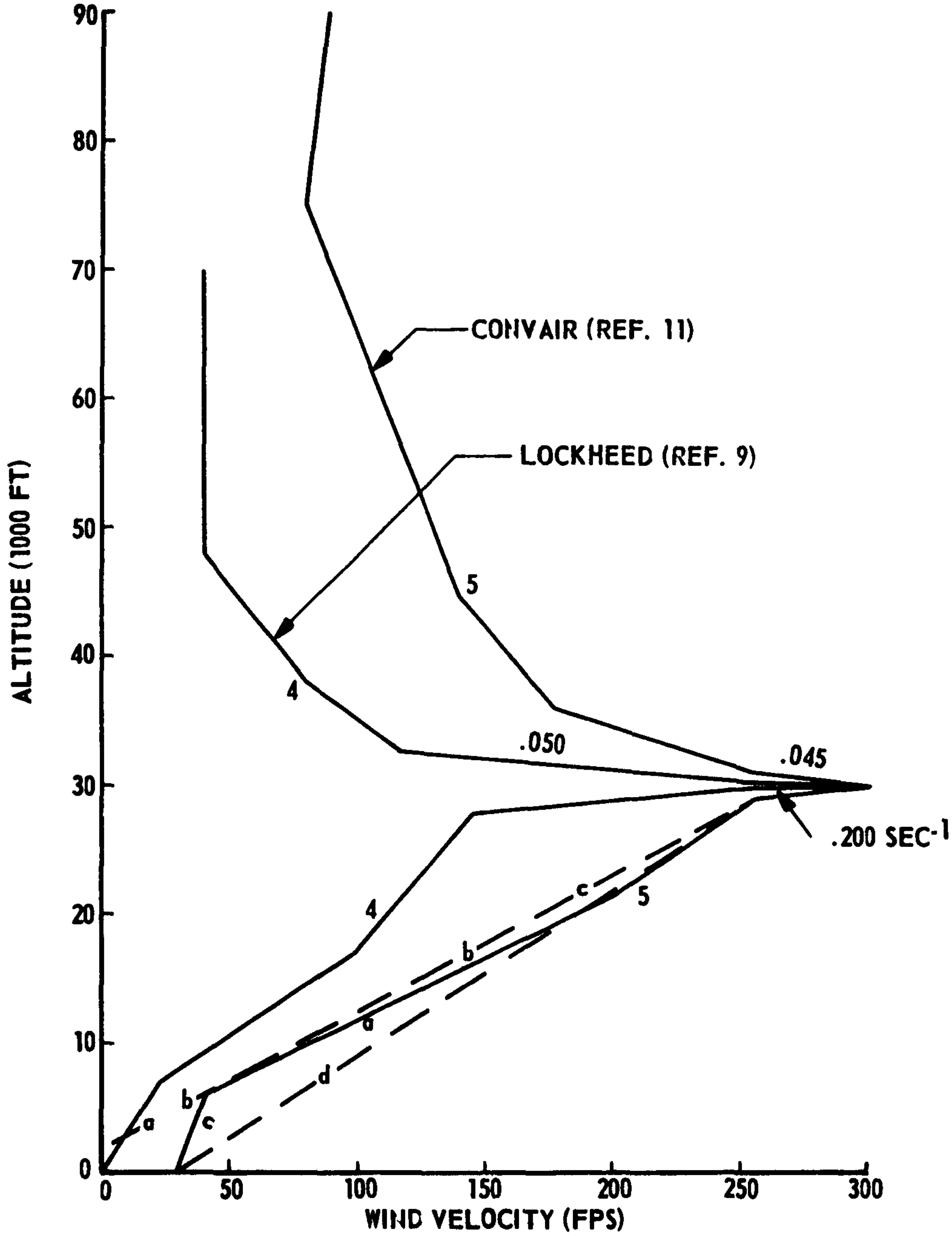


Figure 4 Typical Design Wind Profiles For 1% Probability During Winter

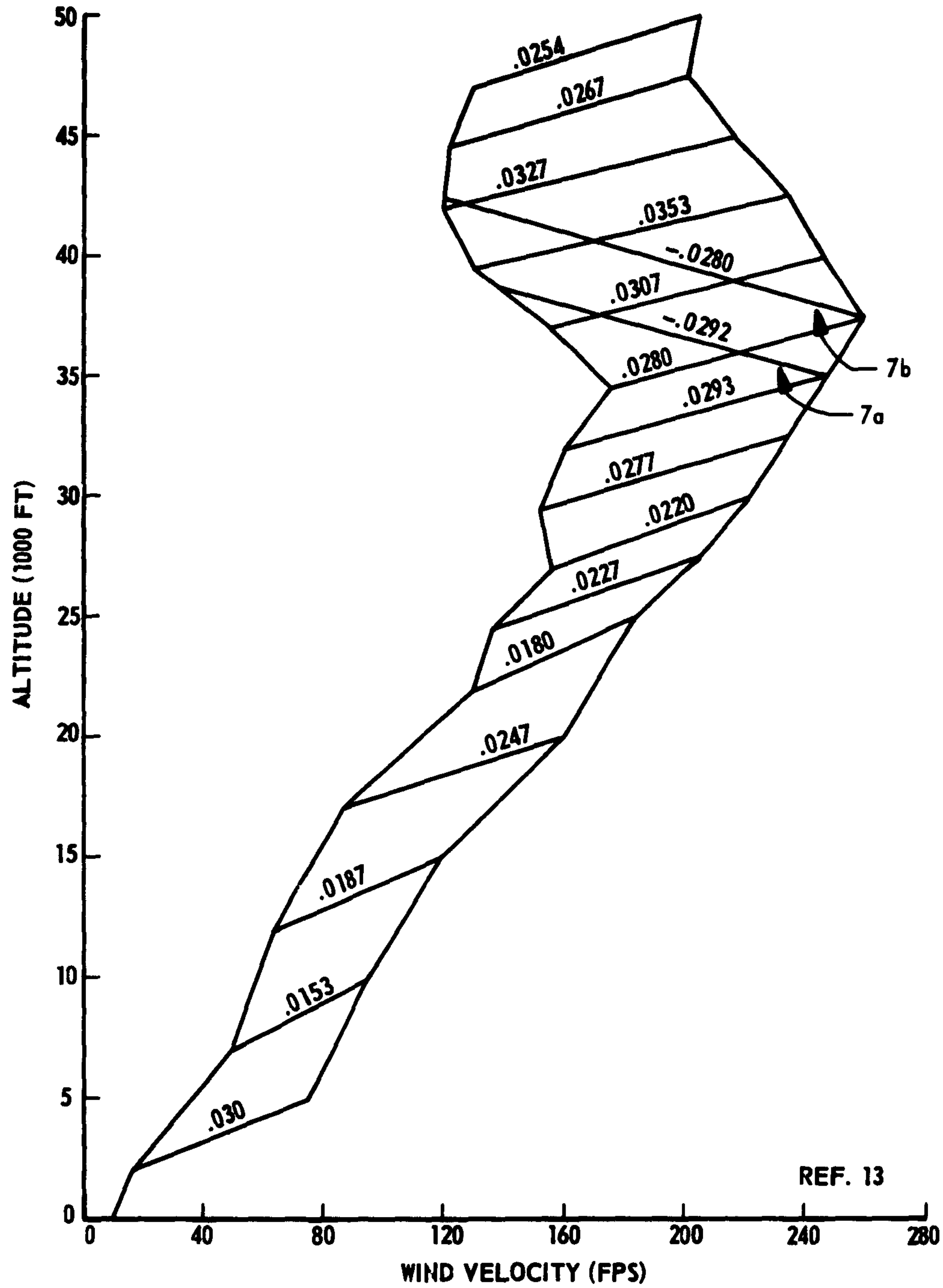


Figure 5 Avidyne Wind Profiles For 1% Probability During Winter

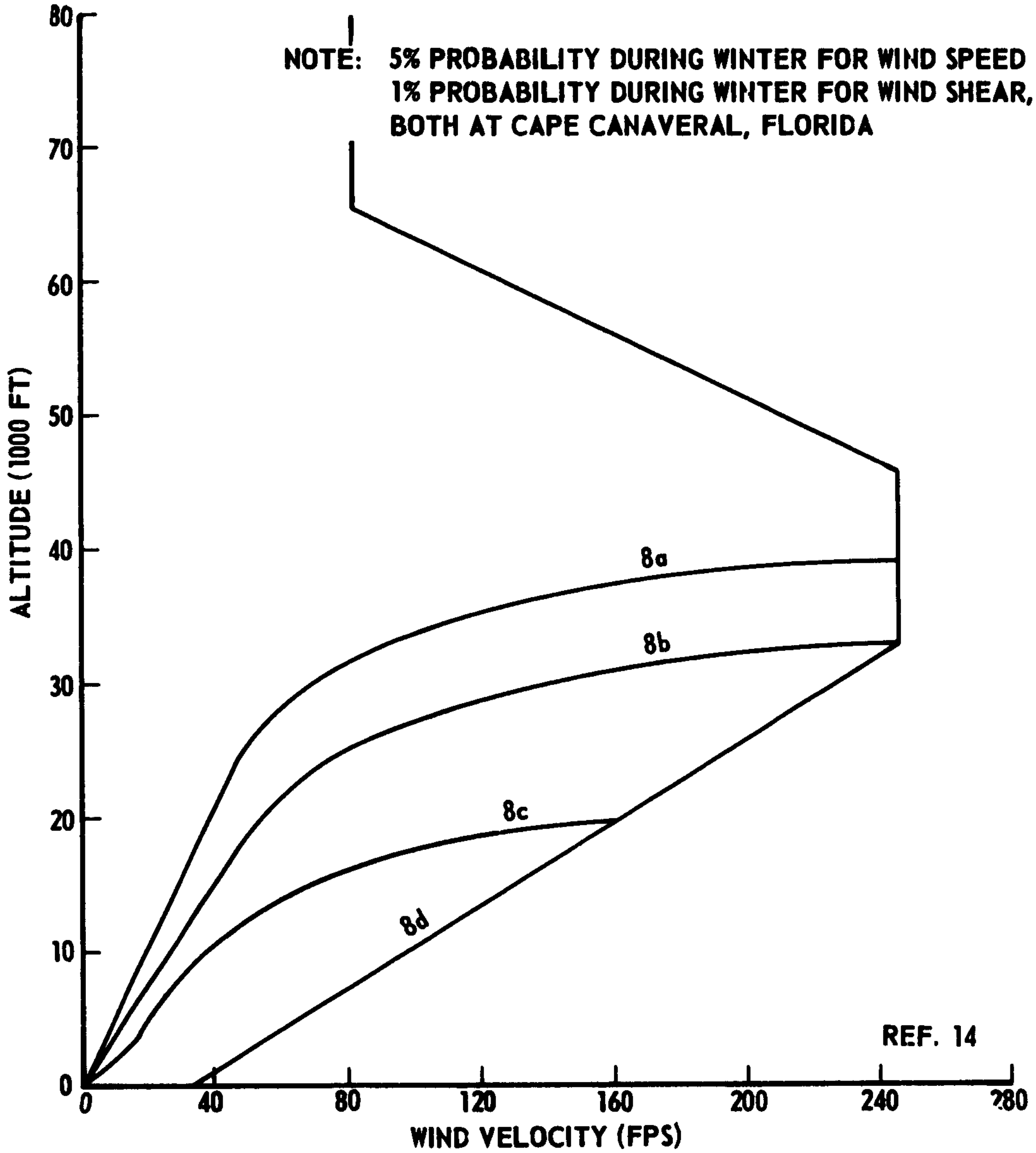


Figure 6 Marshall SFC Wind Profiles For Saturn Vehicle

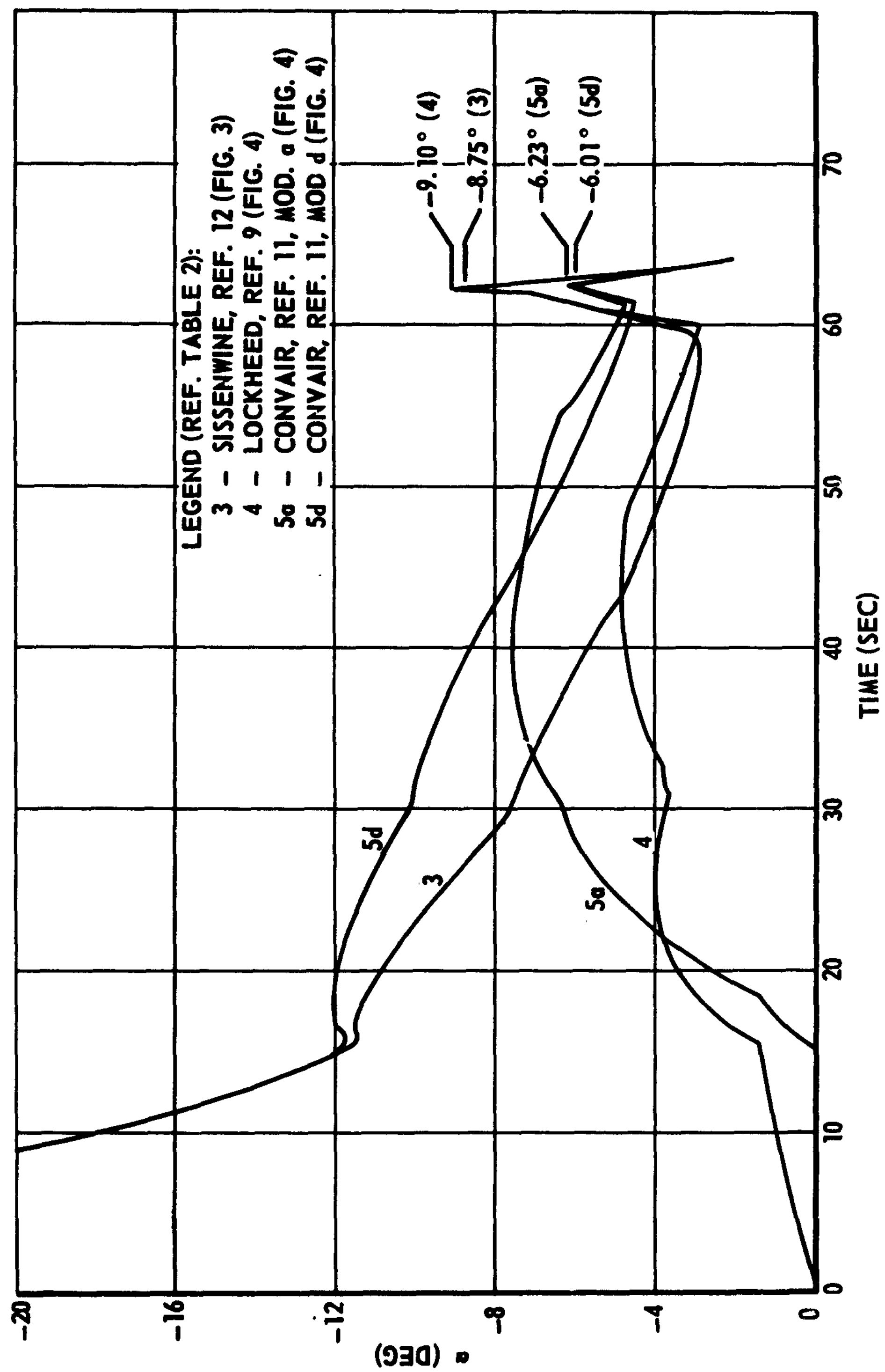


Figure 7 Tail Wind Response For Various Wind Profiles (Vehicle A)

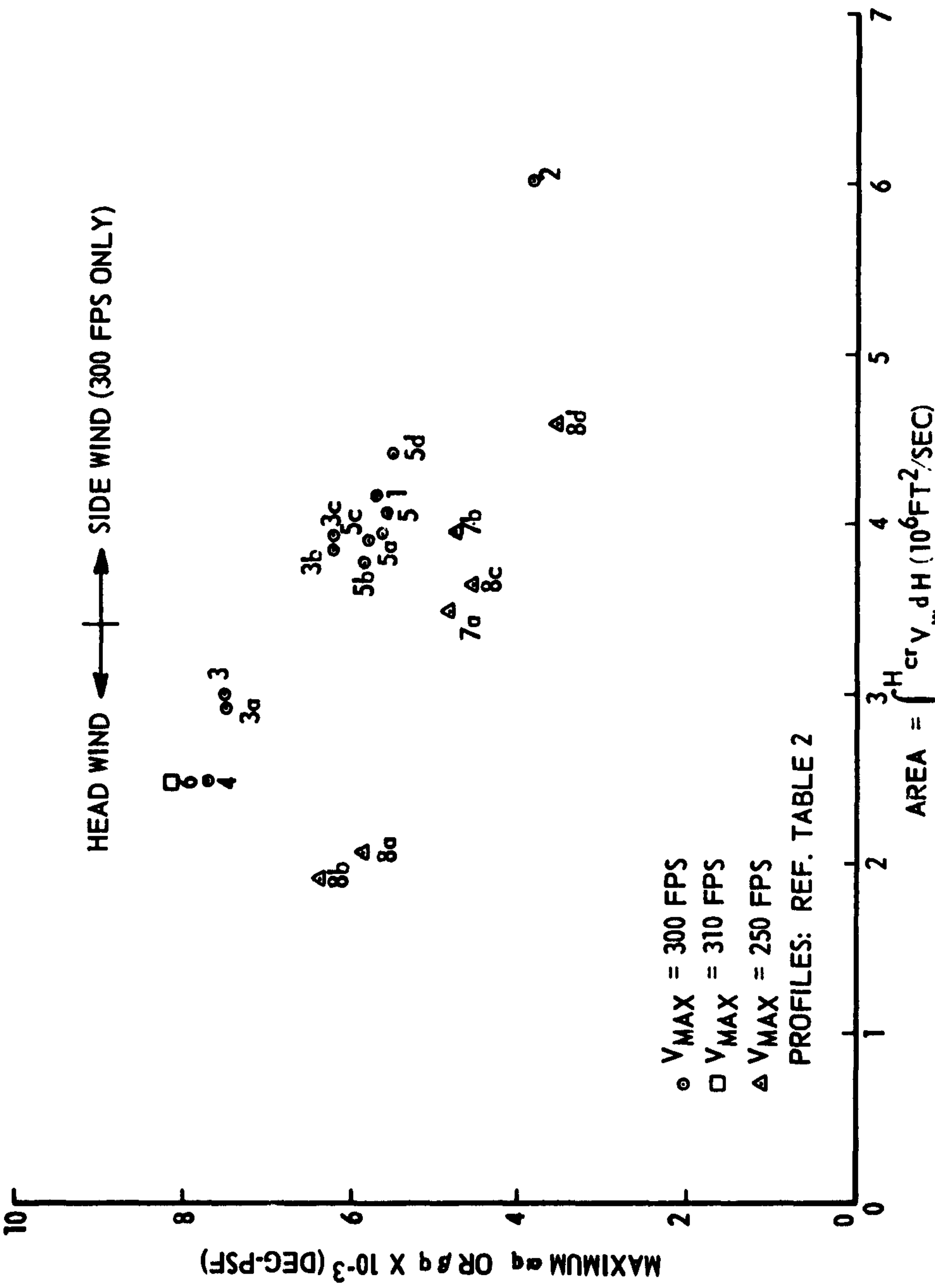


Figure 8 Response For Wind Profiles From Literature (Vehicle A)

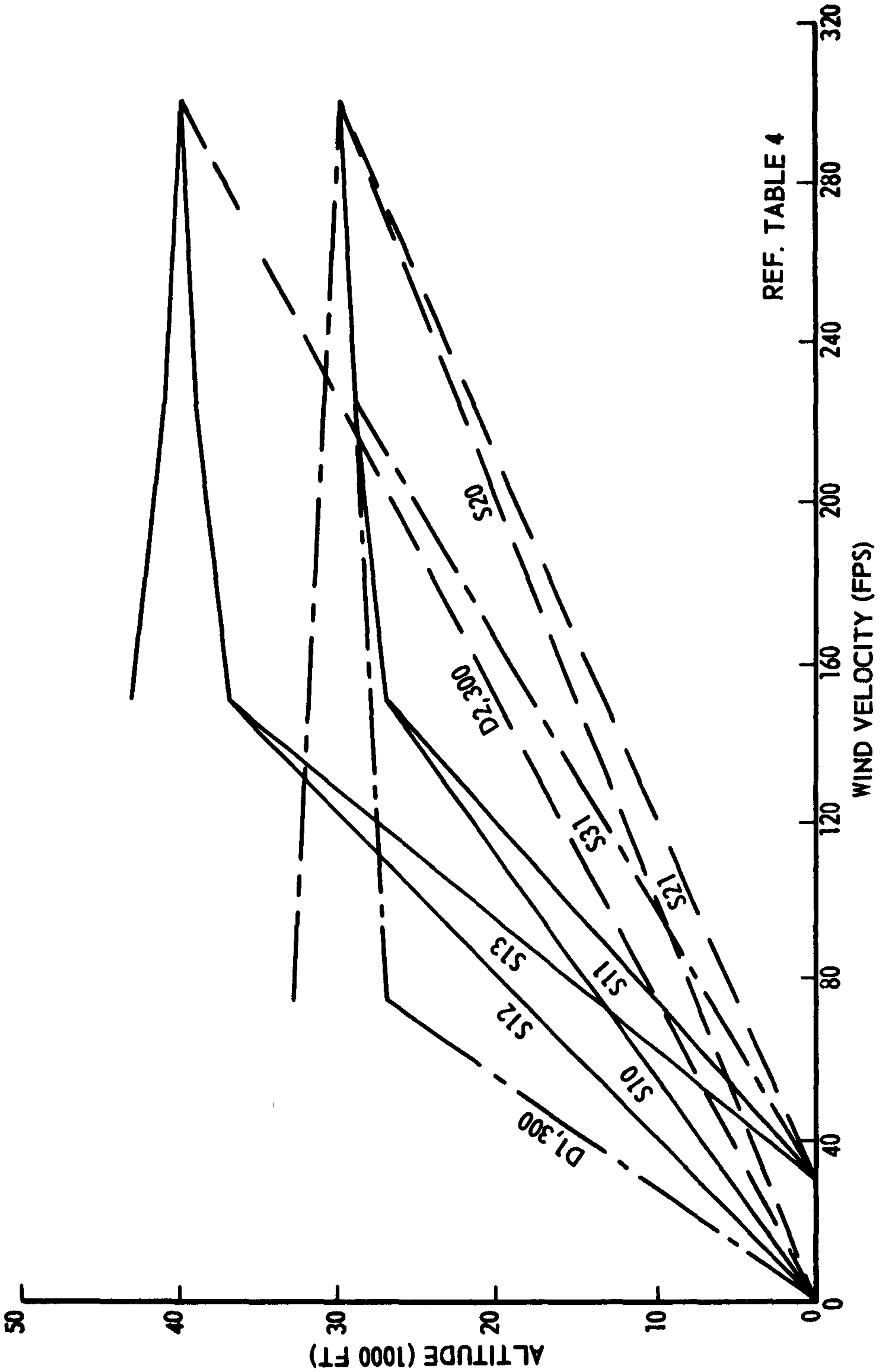


Figure 9 Synthetic Profiles For Parameter Study

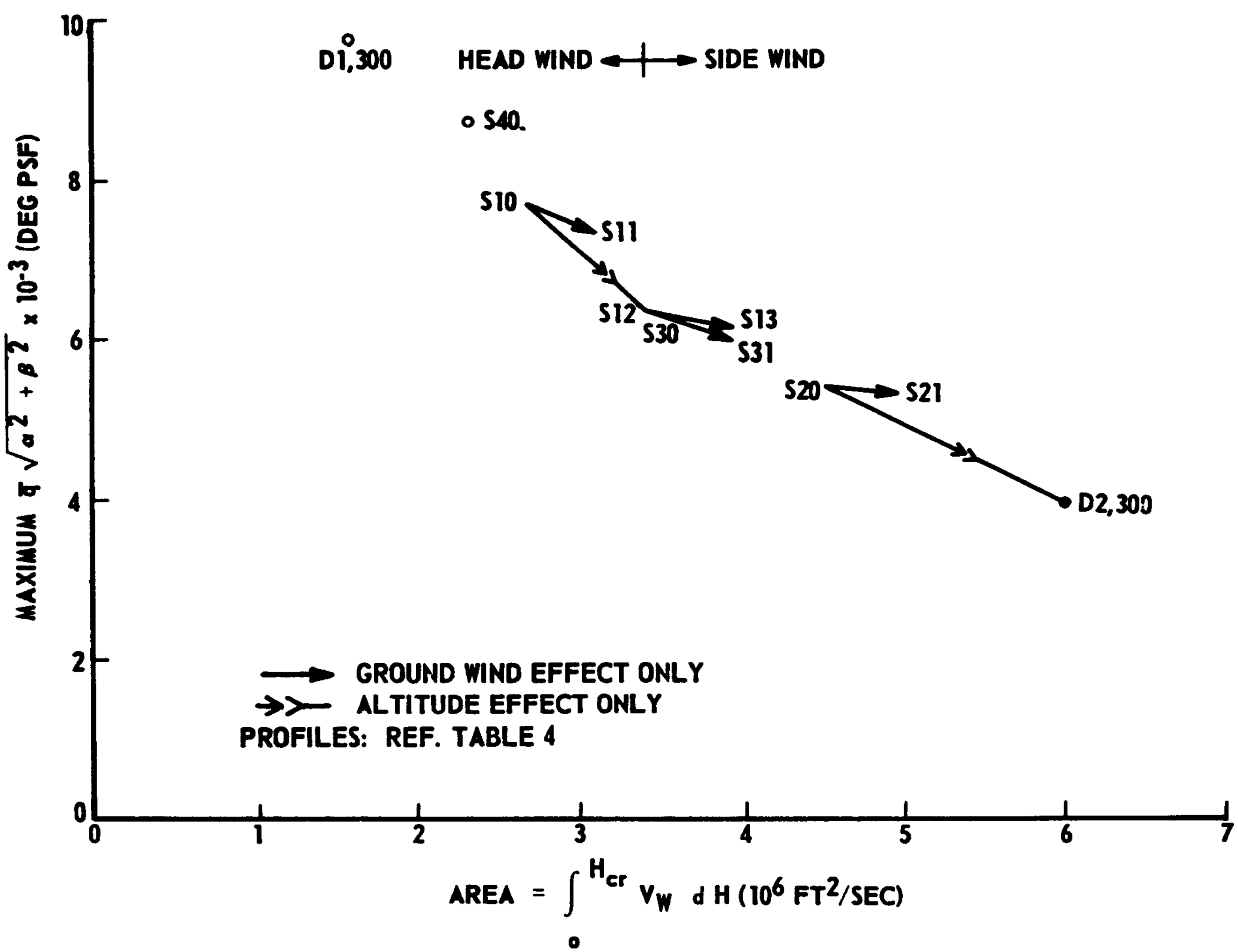


Figure 10 Response For Parameter Study Profiles (Vehicle A)

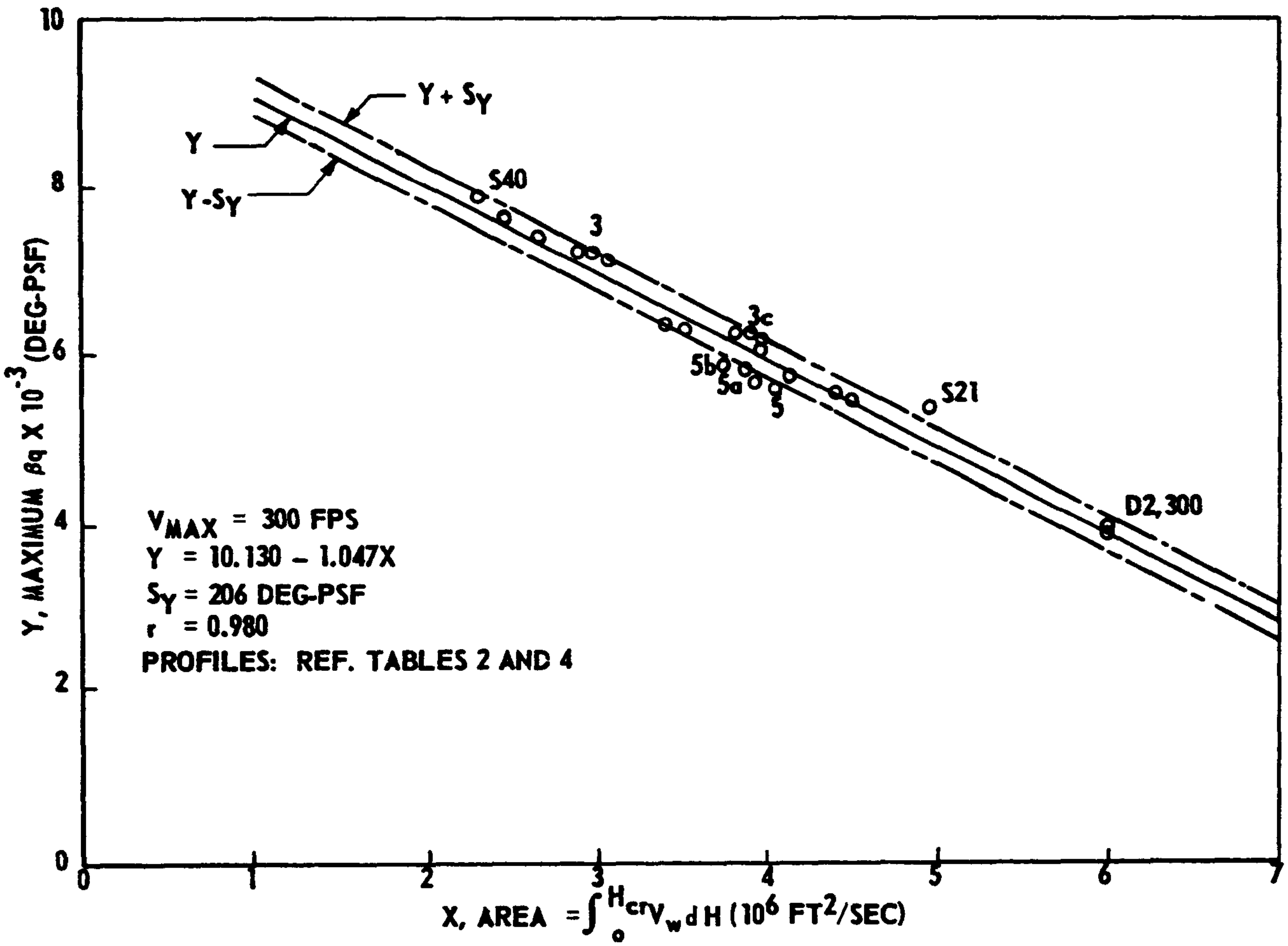


Figure 11 Regression Curve Of Rigid Body Side Wind Response (Vehicle A)

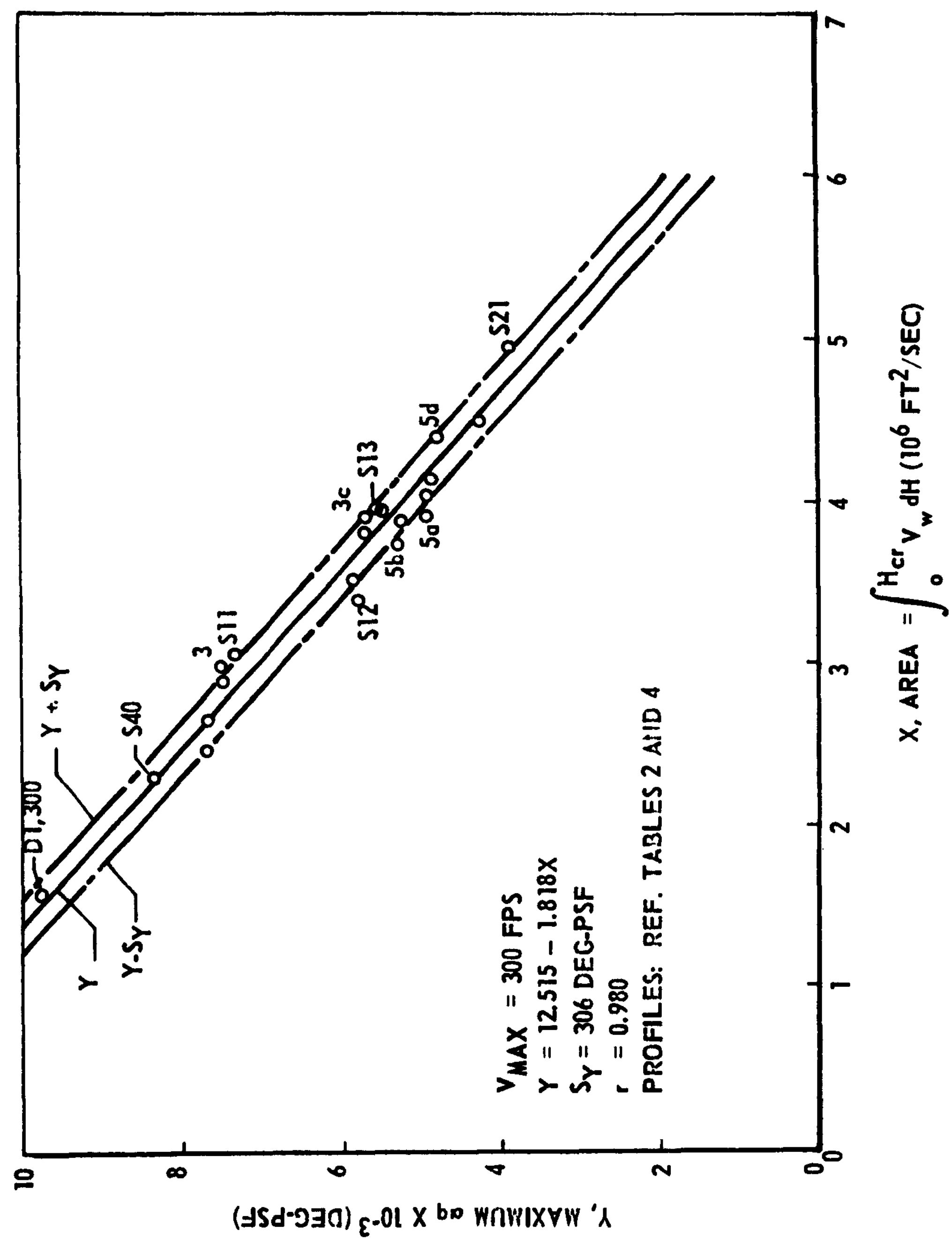


Figure 12 Regression Curve Of Rigid Body Head Wind Response (Vehicle A)

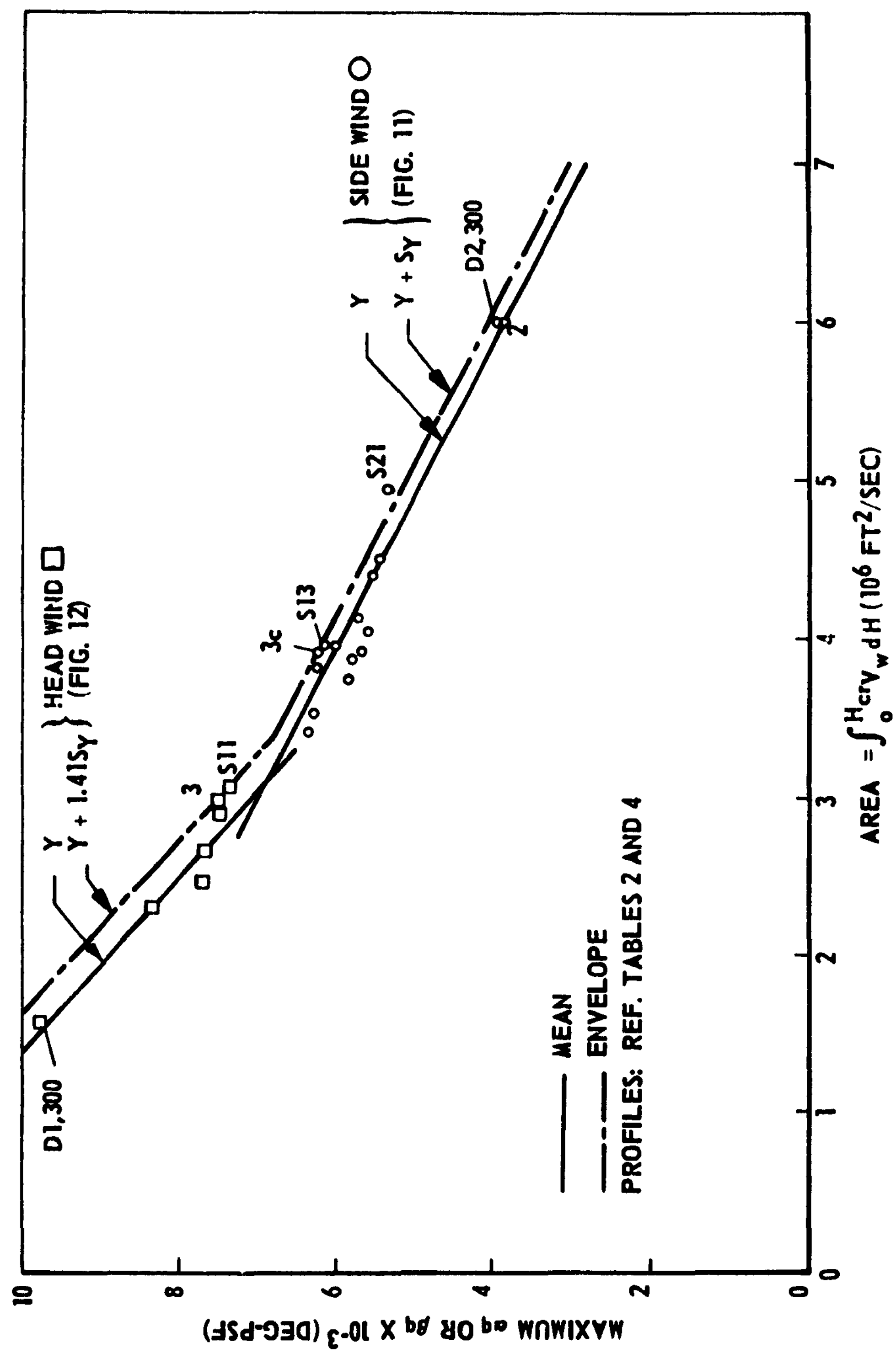


Figure 13 Regression Curve Of Rigid Body Response For Maximum Wind Velocity Of 300 FPS (Vehicle A)

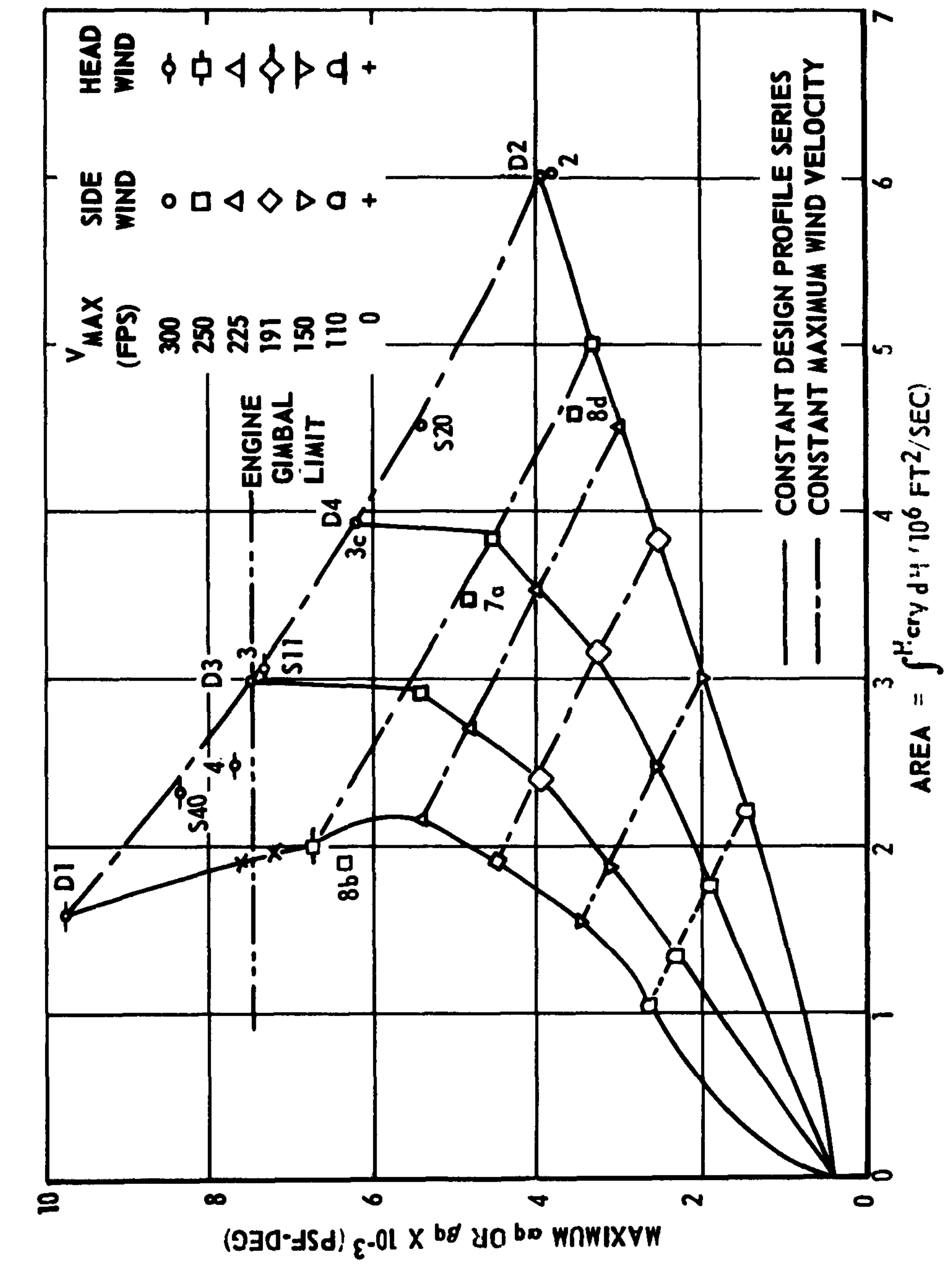


Figure 14 Rigid Body Response For Design Wind Profiles ~ Vehicle A

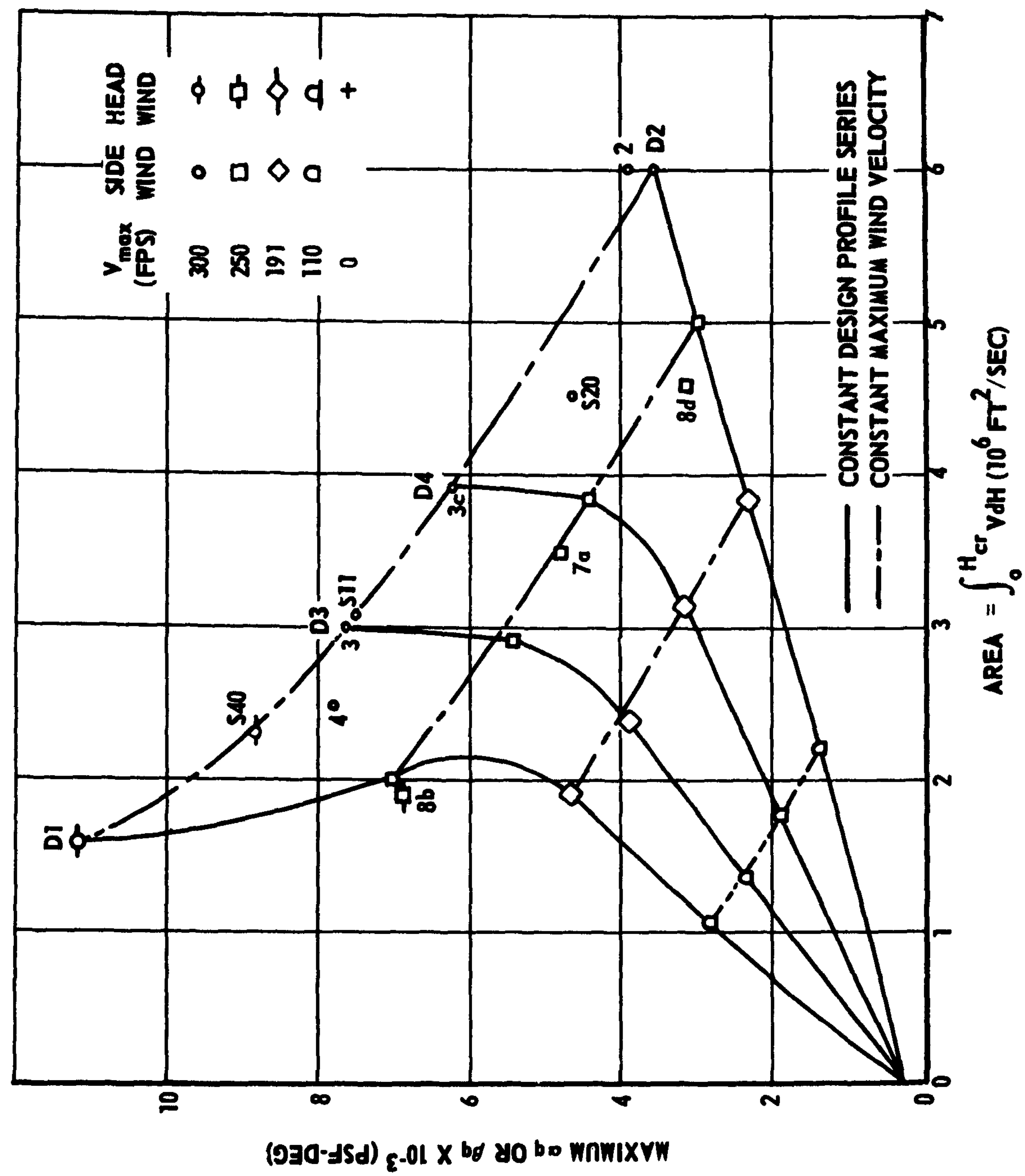


Figure 15 Rigid Body Response For Design Wind Profiles ~ Vehicle B

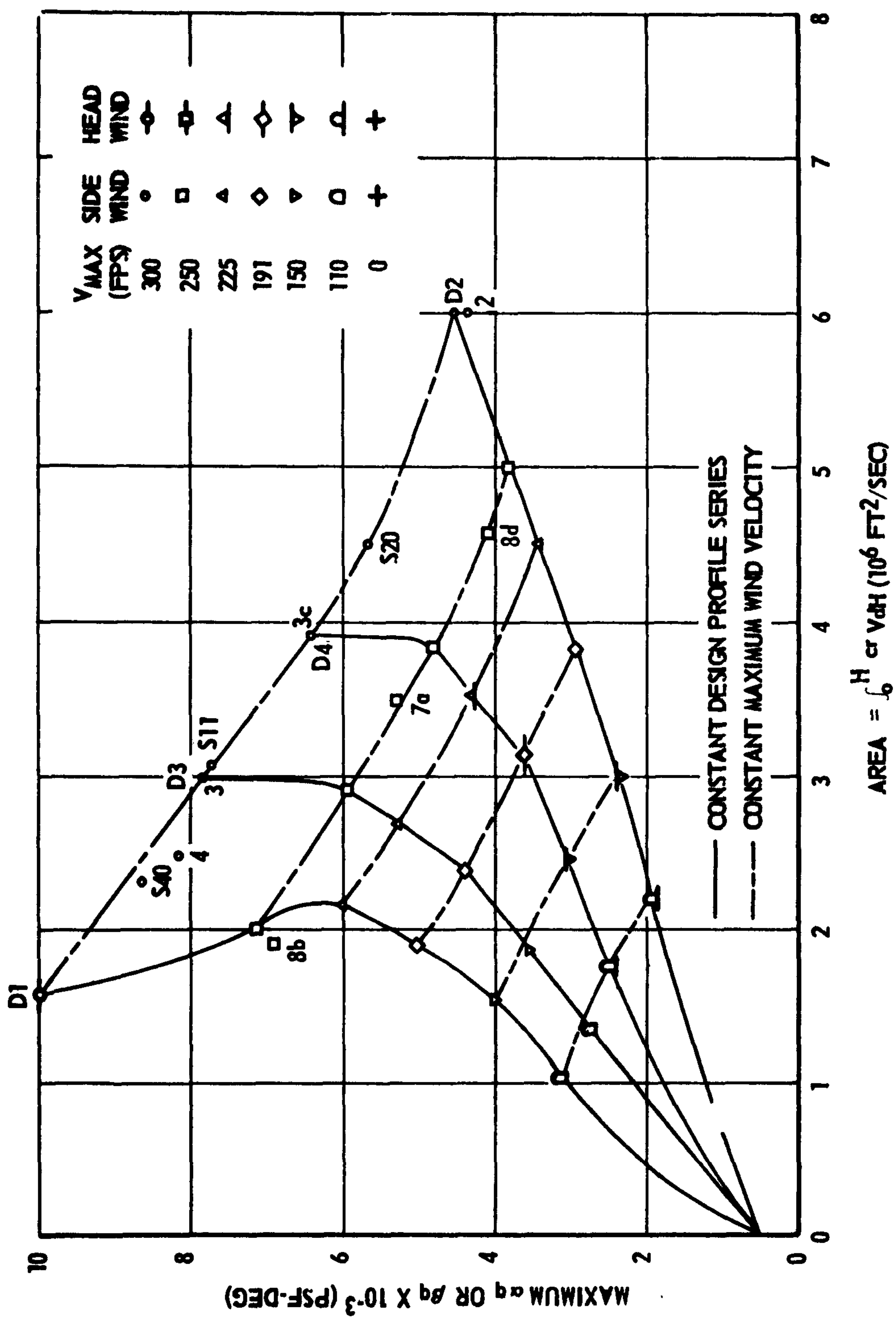


Figure 16 Rigid Body Response For Design Wind Profiles ~ Vehicle C

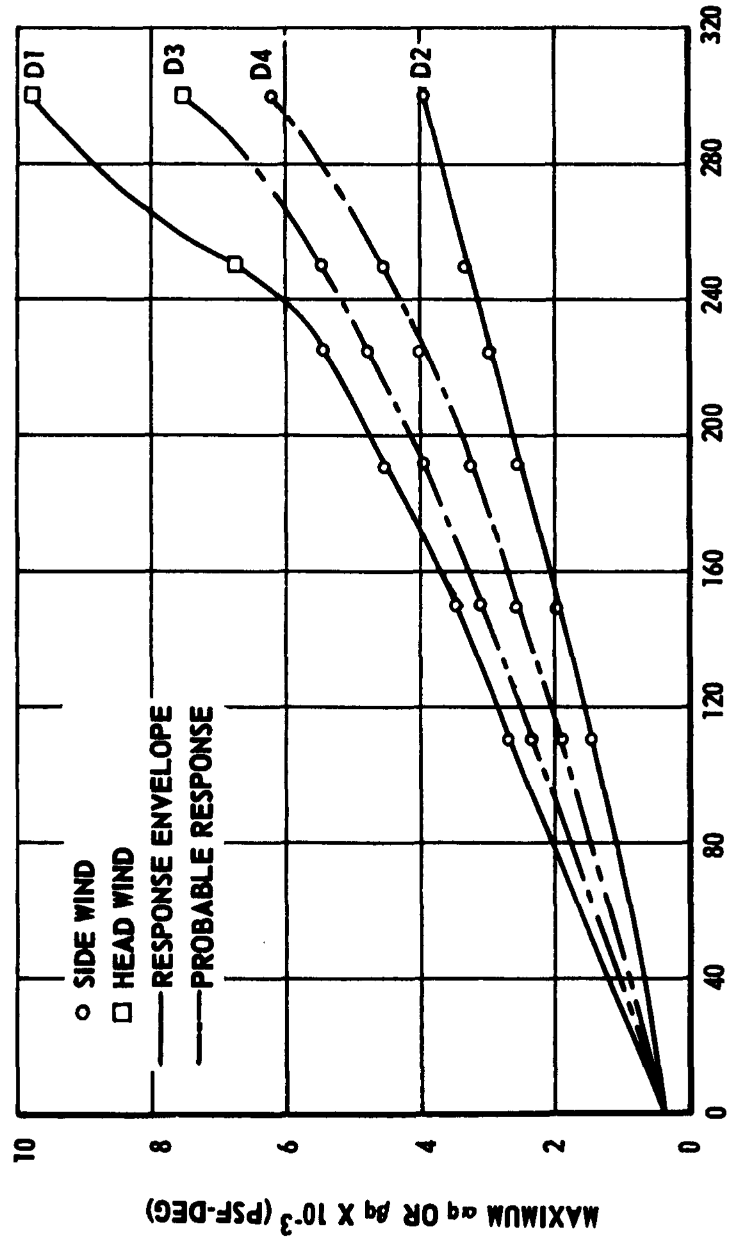


Figure 17 Design Wind Response ~ Vehicle A

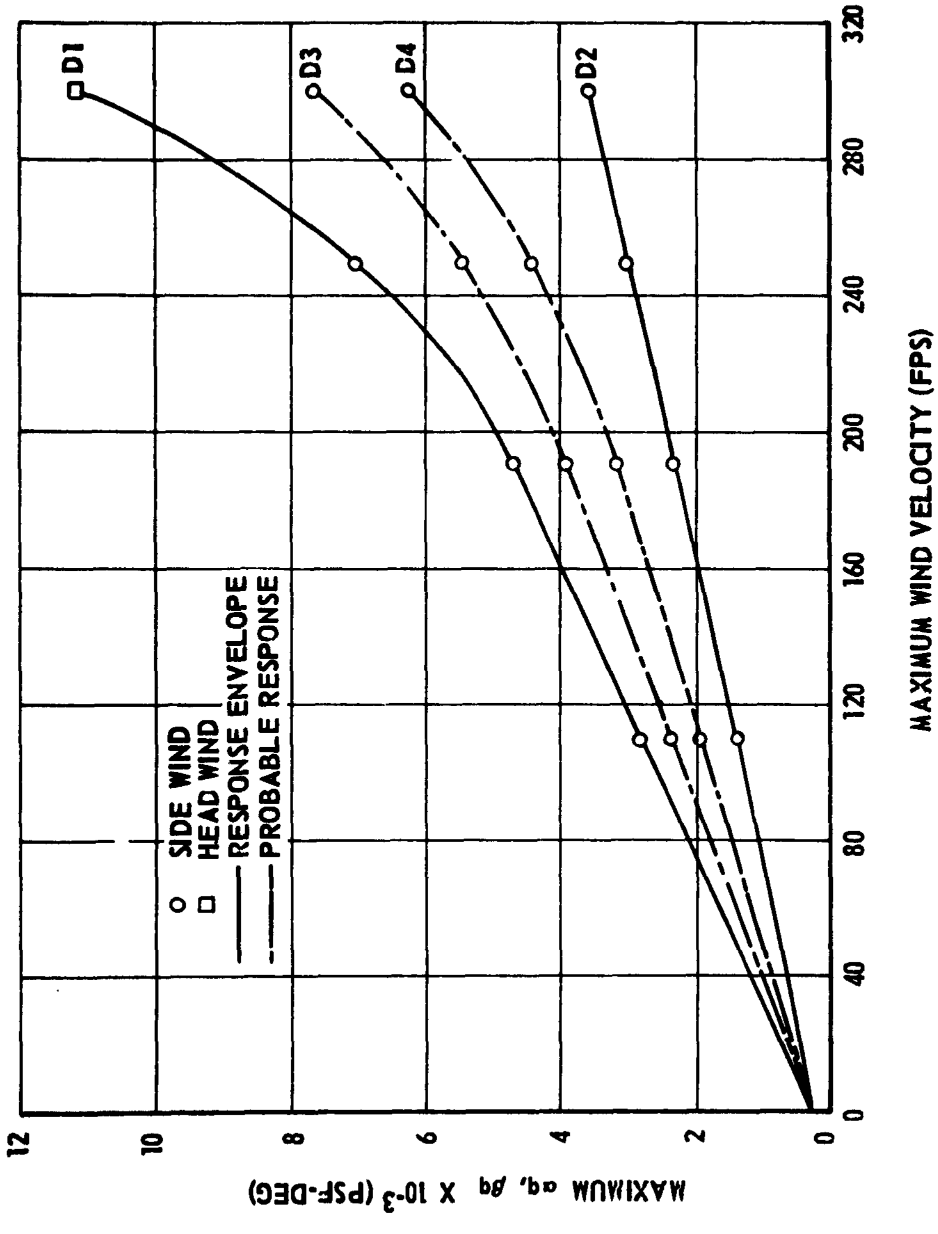


Figure 18 Design Wind Response ~ Vehicle B

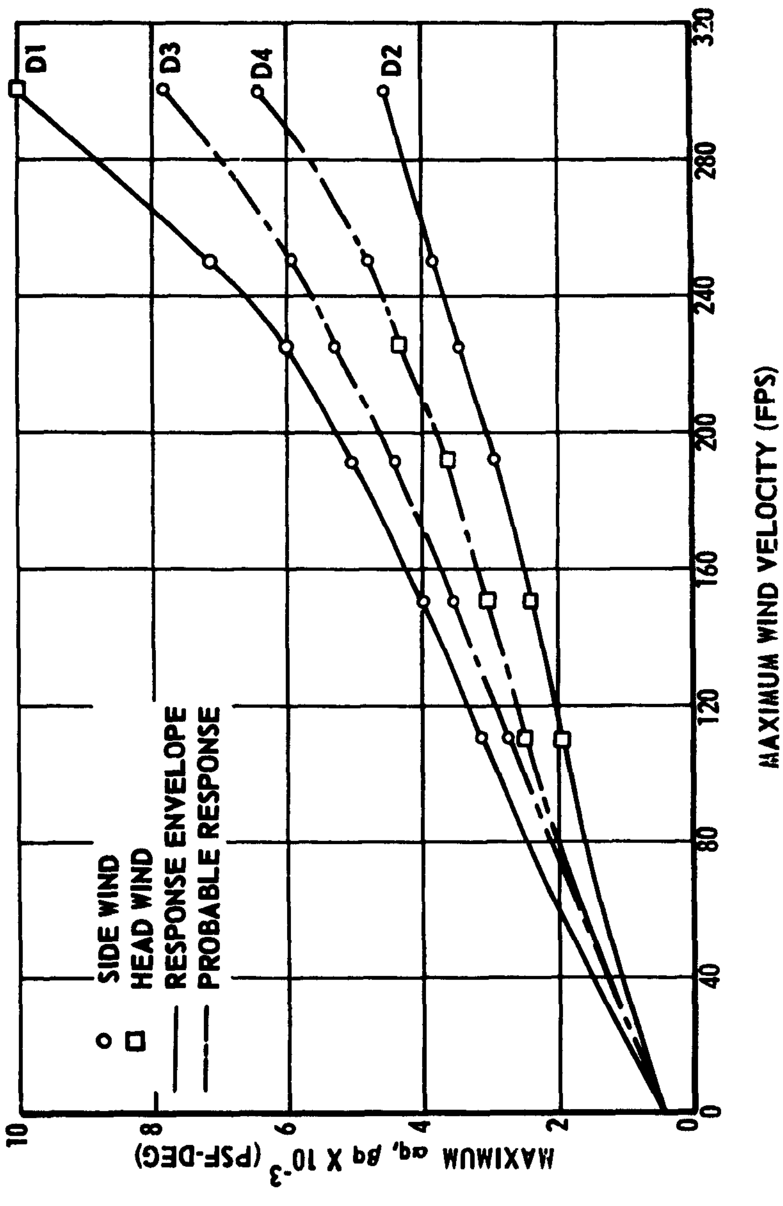


Figure 19 Design Wind Response ~ Vehicle C

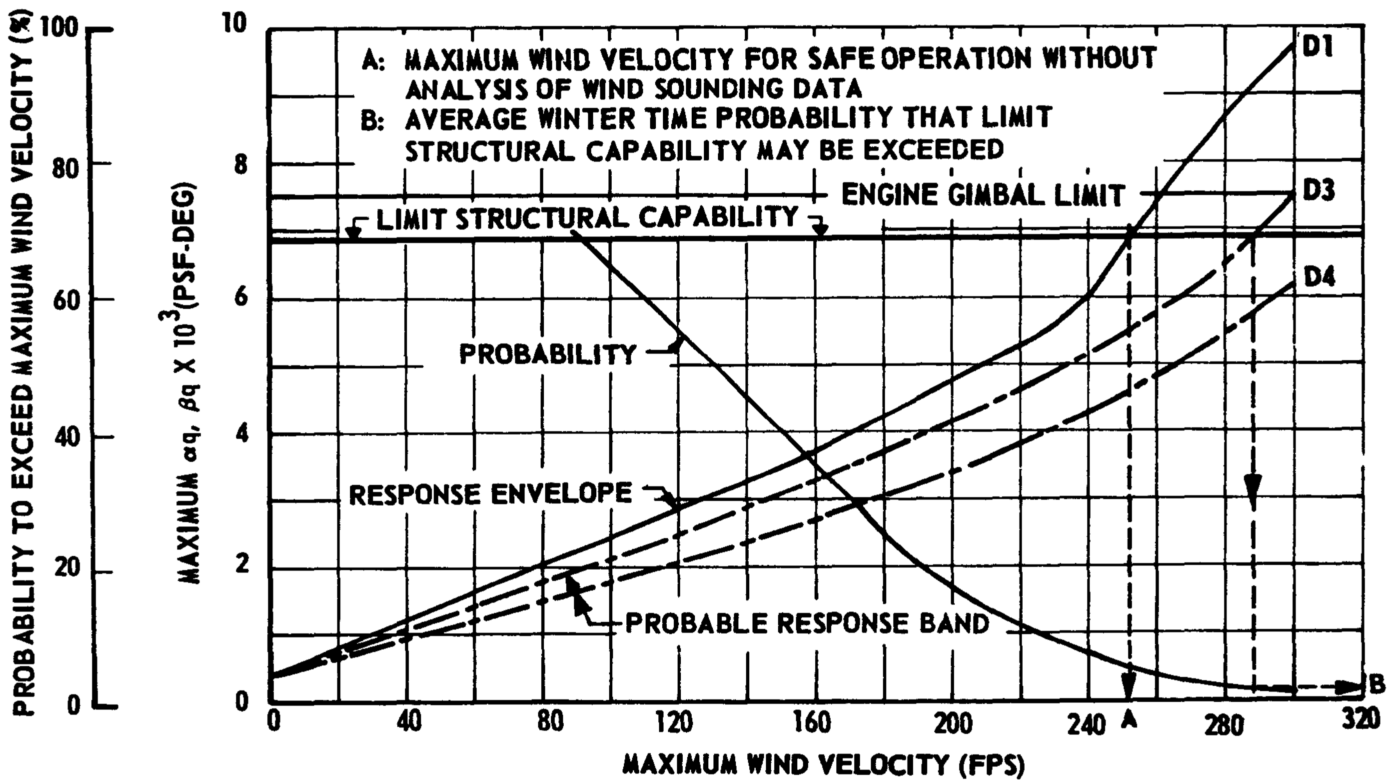


Figure 20 Design Diagram For Wind Shear Response ~ Vehicle A

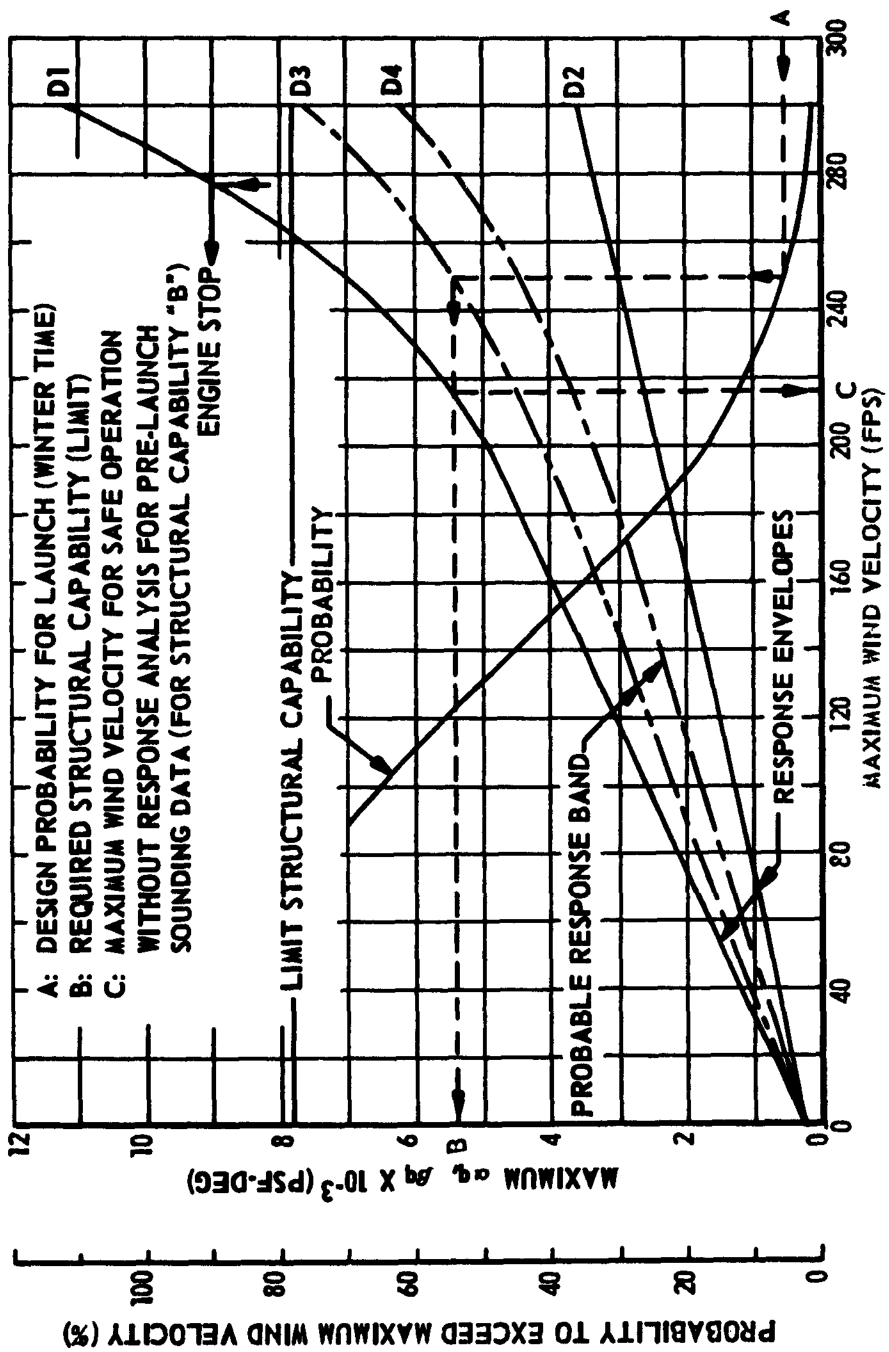


Figure 21 Design Diagram For Wind Shear Response ~ Vehicle B

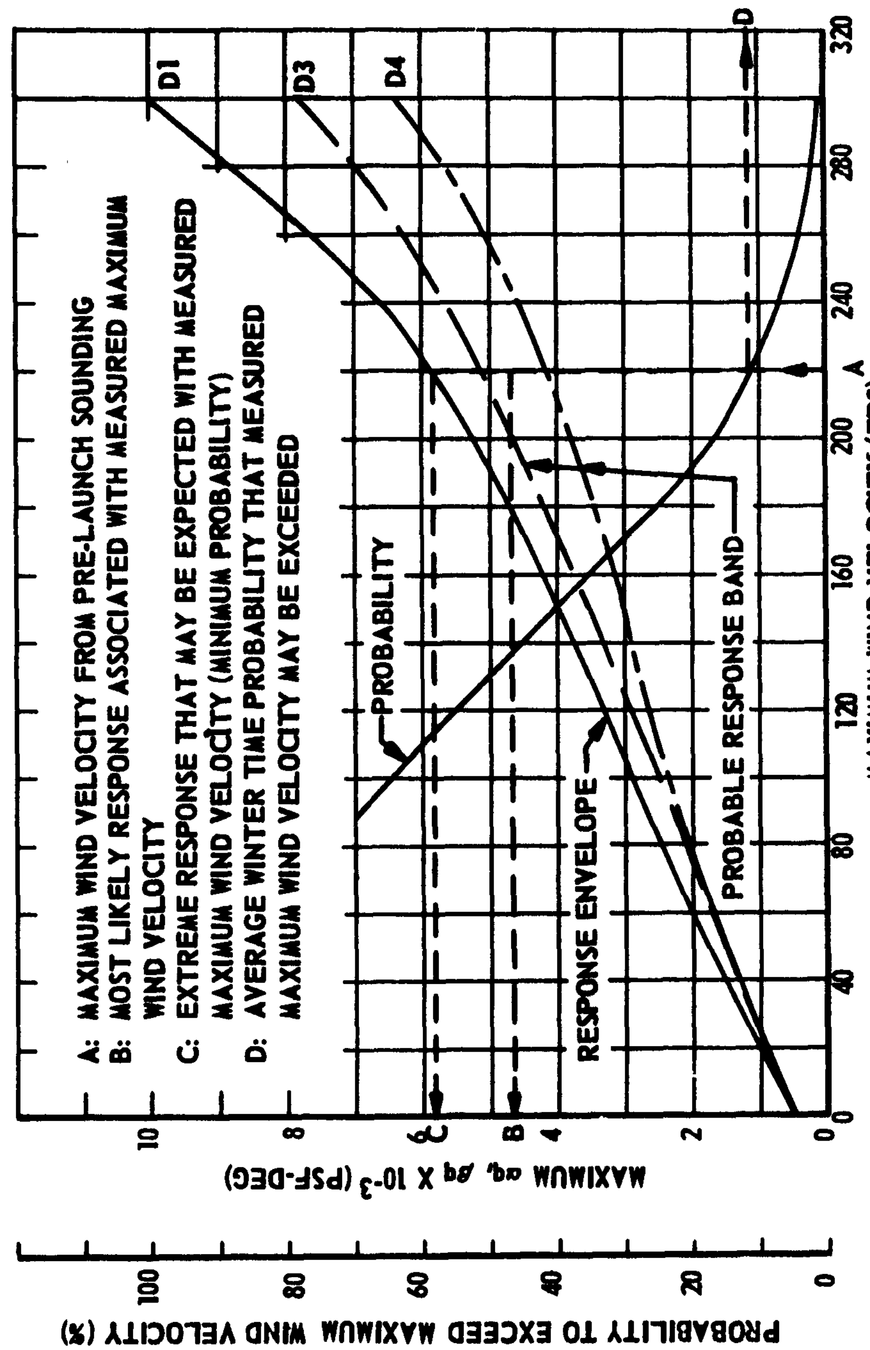


Figure 22 Design Diagram For Wind Shear Response ~ Vehicle C

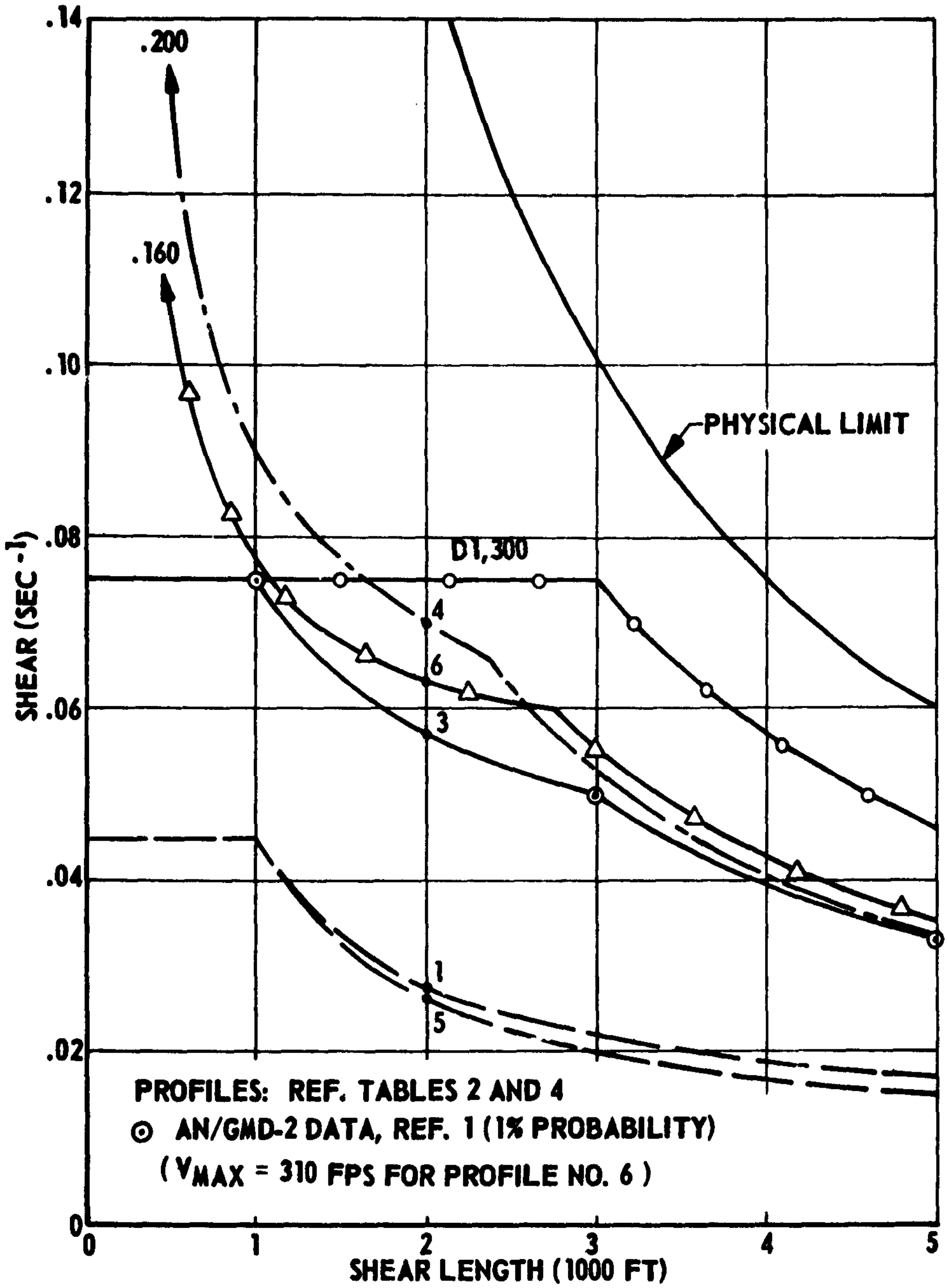


Figure 23 Shear Versus Shear Length For Wind Profiles With Maximum Wind Velocity Of 300 FPS

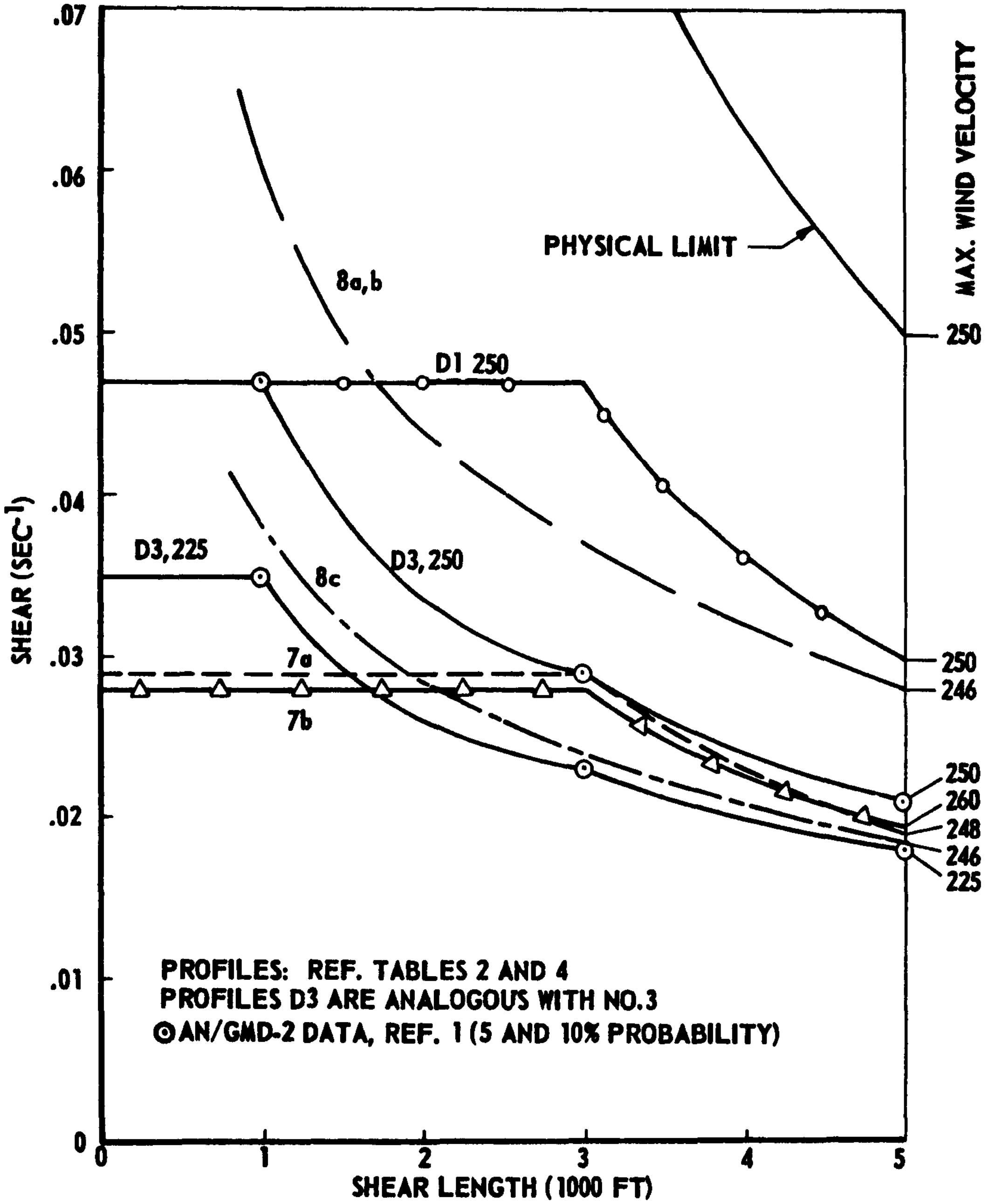


Figure 24 Shear Versus Shear Length For Wind Profiles With Maximum Wind Velocity of 225 to 260 FPS

APPENDIX A
DEVELOPMENT OF DESIGN WIND PROFILE SERIES

The design diagrams for wind shear response (Figs. 20, 21, and 22) logically should be obtained for the mean integrated area and its confidence limits at the desired level of confidence. However, as long as the required statistics are not available, a method of estimation must be provided. This is accomplished by means of four design profile series. Each of the four basic profiles has a rational basis, permitting it to be expanded into a series with maximum wind velocity as the argument. Detailed information for their construction is provided in this Appendix.

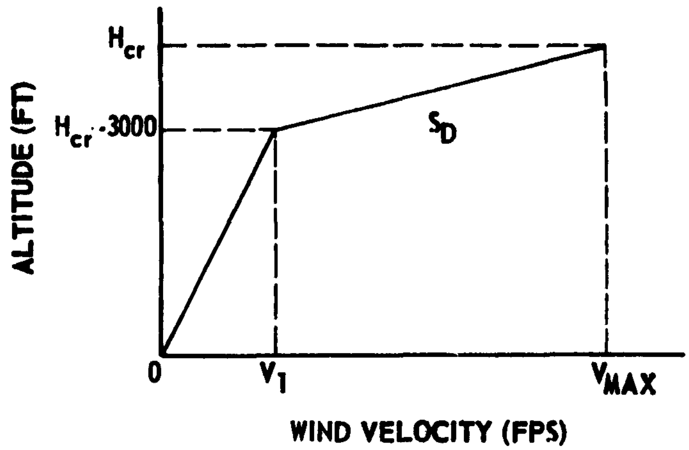
DESIGN PROFILES D1

This profile series has two parameters, maximum wind velocity and shear. These two parameters are related as shown in Table 1 except that only the 1000-ft. shear is used and expanded to 3000-ft. shear length. This results in a large incremental wind velocity with a high shear. It is a very extreme condition resulting in a minimum integrated area. The parameters are:

S_D : 1000-ft shear (sec^{-1}) associated with V_{max} (Table 1)

$V_1 = V_{max} - 3000 S_D$ (fps), Wind velocity at ($H_{cr} - 3000$) ft.

$$A = \int_o^{H_{cr}} V\,dH = 0.5\, V_1 H_{cr} + 1500\, V_{max} \quad (ft^2/sec)$$



Design Profile D_1

These profiles are critical for minimum area or H_{cr} in the range of 30, 000 ft. For H_{cr} = 30, 000 ft.

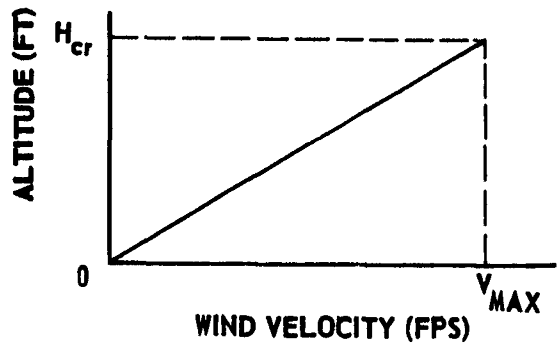
$$A = 1500 \times (10\, V_1 + V_{max})\ ft^2/sec.$$

Typical values of the parameters are tabulated in Table 5 and plotted in Figure 26.

DESIGN PROFILES D2

Design profiles D2 have only one parameter, maximum wind velocity. The basic profile simply is a constant shear from zero ground wind to maximum wind velocity at critical altitude. These profiles are critical for maximum integrated area and, therefore, the critical altitude should be large, 40, 000 ft or greater. The integrated area is given by:

$$A = \int_o^{H_{cr}} V\, dH = 0.5\, V_{max}\, H_{cr}\ (ft^2/sec)$$



Design Profile D_2

Typical values of this area are presented in Table 6.

DESIGN PROFILES D3 AND D4

The design wind profile series D3 and D4 (see Fig. 27 for examples) are synthetic reconstructions of atmospheric wind profiles using the AN/GMD-2 data from Ref. 1 (Table 1). They correspond to the Sissenwine profile No. 3 (design profile D3, 300 is identical) and differ from this one only in critical altitude (D4 series) and the property to have a specific wind profile rationally related to any maximum wind velocity. The purpose of the D3 and D4 profile series is to approximate the mean of the statistical distribution of the integrated area. Both profile series D3 and D4 are used in order to obtain a "band" which may be expected to bracket the mean integrated area. Therefore, the D3 series is associated with smaller integrated areas (relatively low critical altitude) and the D4 series with larger integrated areas (relatively high critical altitude). Another reason for the two series is that the altitude of maximum response and the most likely altitude of maximum wind velocity usually do not coincide. With two series, the effect of both may be accounted for.

The parameters for the D3 and D4 design profile series are (see sketch):

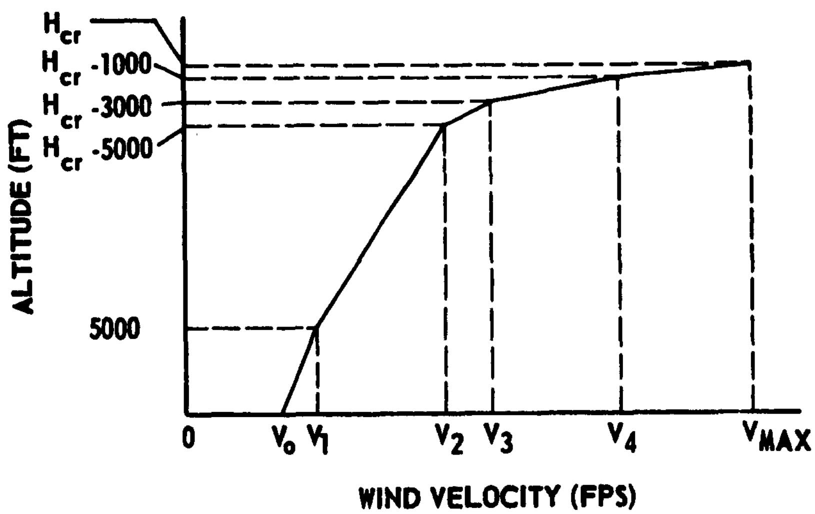
$$V_4 = V_{max} - 1000S_{1000}$$

$$V_3 = V_{max} - 3000S_{3000}$$

$$V_2 = V_{max} - 5000S_{5000}$$

$$\left.\begin{array}{l} V_1 \\ V_o \end{array}\right\} \text{ Estimated from available data}$$

$$A = \int_o^{H_{cr}} VdH = 2500\,V_o + V_1\,(0.5H_{cr} - 2500) + V_2\,(0.5H_{cr} - 4000) + 2000V_3 + 1500V_4 + 500V_{max}$$



Design Profile D_3 and D_4

where V_{max}, S_{1000}, S_{3000}, and S_{5000} are obtained from Table 1. Typical values of the parameters are tabulated in Table 7 and plotted in Figure 28.

Table 5

PARAMETERS FOR DESIGN PROFILES D1

V_{max}, fps	S_D, sec^{-1}	V_1, fps	A @ H_{cr} = 30,000 ft 10^6 ft^2/sec
300	0.0750	75.0	1.575
277	0.0624	89.8	1.763
250	0.0470	109.0	2.010
225	0.0369	114.4	2.053
191	0.0280	107.0	1.892
[illegible]	0.0241	97.7	1.720
[illegible]	0.0210	87.0	1.530
[illegible]	0.0188	73.7	1.300
[illegible]	0.0173	58.1	1.037
[illegible]	0.0155	41.5	0.755
[illegible]	0.0144	[illegible]	0.670
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	14.3	[illegible]
[illegible]	0.0046	6.2	0.123
	Extrapolated		

Table 6

PARAMETERS FOR DESIGN PROFILES D2

V_{max}, fps	$A \times 10^{-6}$, ft^2/sec		
	H_{cr} = 40,000 ft	H_{cr} = 45,000 ft	H_{cr} = 50,000 ft
300	6.00	6.750	7.500
250	5.00	5.625	6.250
225	4.50	5.063	5.625
191	3.82	4.302	4.775
170	3.40	3.825	4.250
150	3.00	3.375	3.750
130	2.60	2.925	3.250
110	2.20	2.475	2.750
88	1.76	1.980	2.200

Table 7

PARAMETERS FOR DESIGN PROFILES D3 AND D4

V_{max}	V_4	V_3	V_2	V_1	V_0	Area x 10^{-3}, Ft ^{2}/Sec		
H_{cr}	H_{cr}-1000	H_{cr}-3000	H_{cr}-5000	5000 Ft	0 Ft	H_{cr}, 1000 Ft		
fps	fps	fps	fps	fps	fps	30 (D3)	40 (D4)	50 (D4)
300	225	150	135	50	35	2985	3910	4835
277	215	155	141	44	31	2950	3875	4800
250	203	163	142	39	27	2873	3778	4683
225	188	157	136	34	24	2690	3540	4390
191	163	137	120	30	21	2362	3112	3862
170	146	123	107	28	19	2125	2800	3475
150	129	109	93	25	18	1867	2457	3047
130	111	94	78	23	16	1605	2110	2615
110	93	78	64	20	14	1340	1760	2180
88	72	59	47	17	12	1030	1350	1670
80	66	54	42	16	11	937	1227	1517
60	48	38	30	12	9	681	891	1101
40	31	24	18	9	6	440	575	710
20	15	12	8	5	3	215	280	345

EXTRAPOLATED

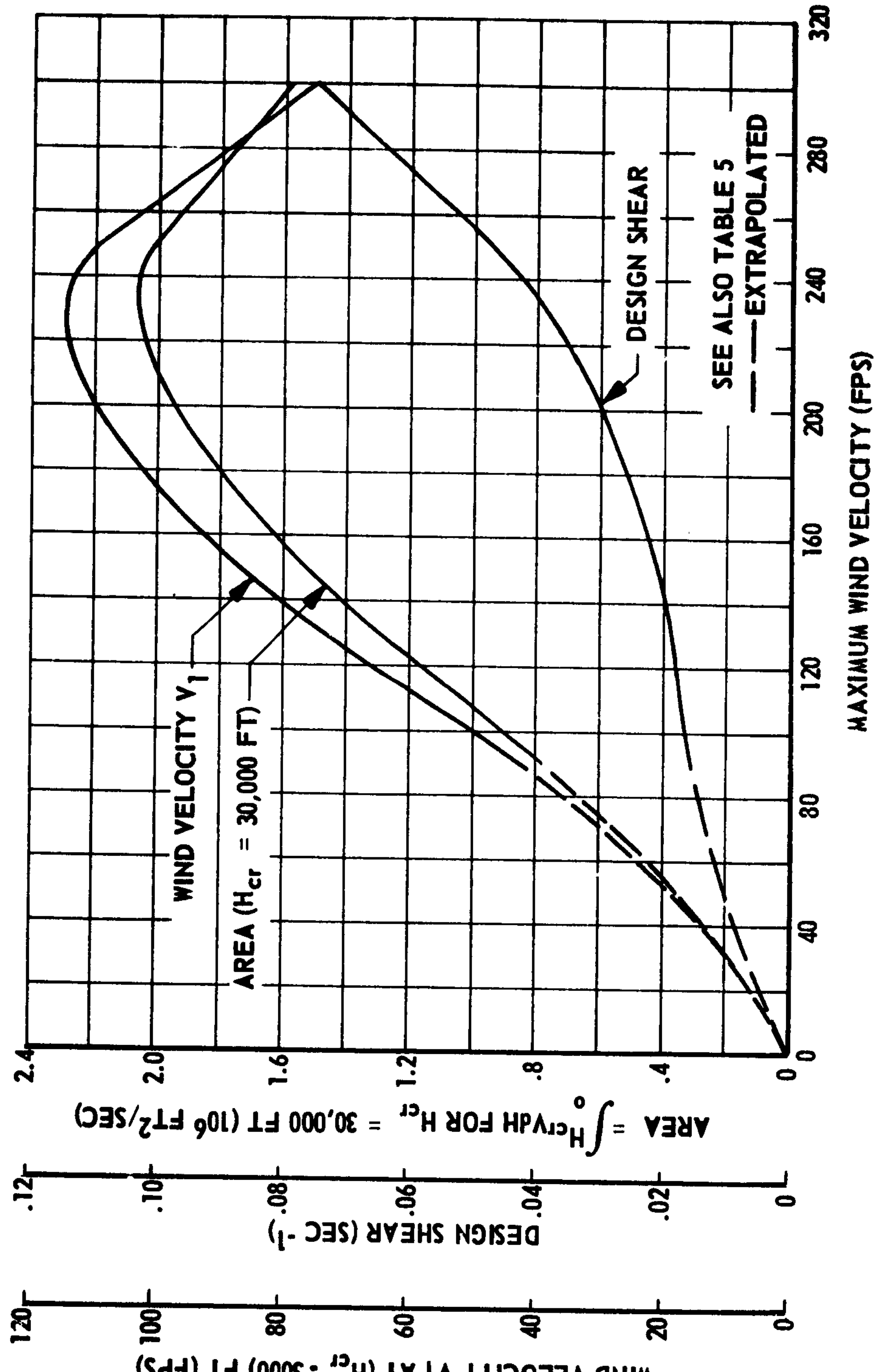


Figure 25 Parameters For Design Wind Profiles D1

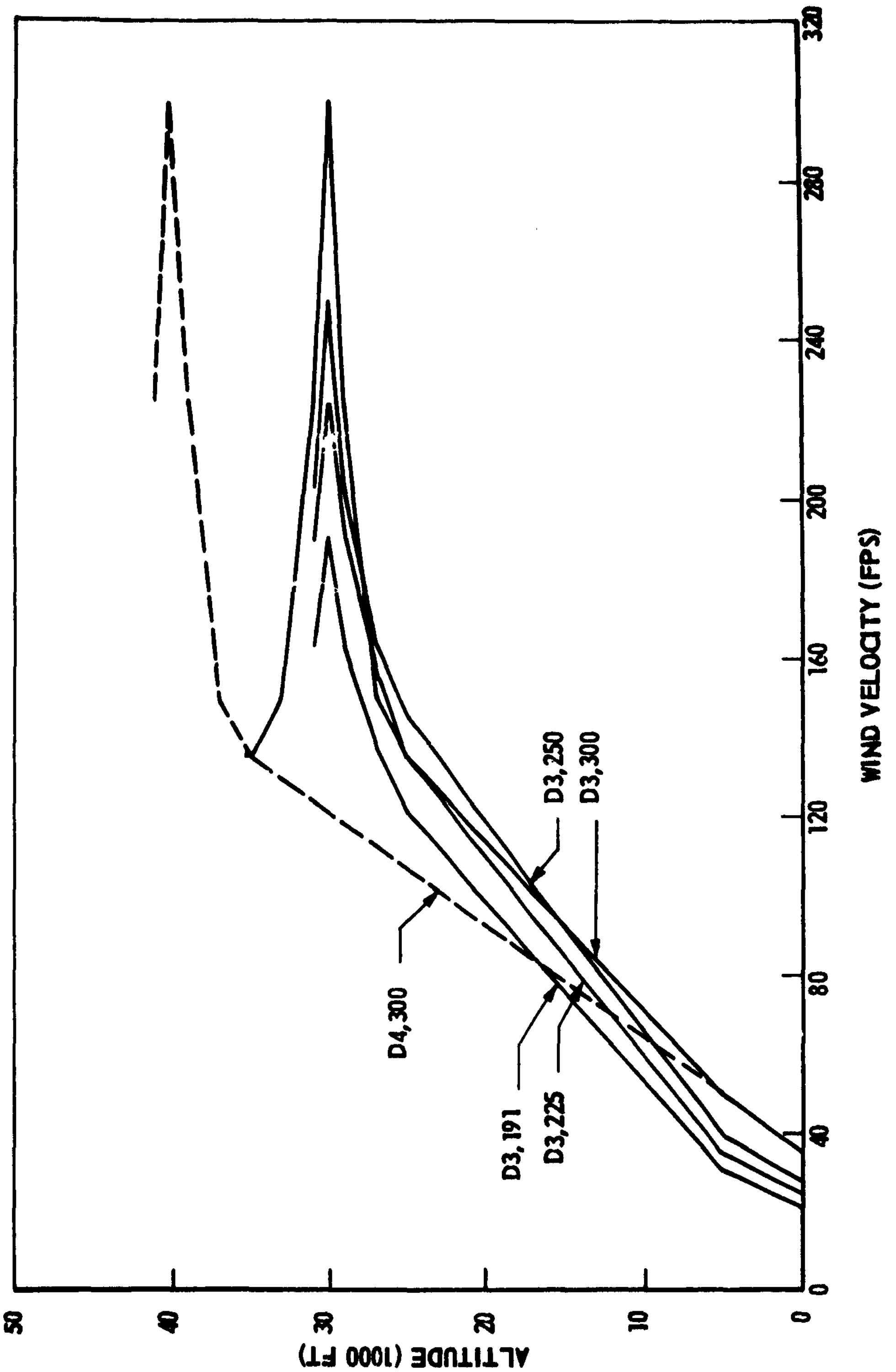


Figure 26 Typical Examples Of Design Wind Profiles D3 and D4

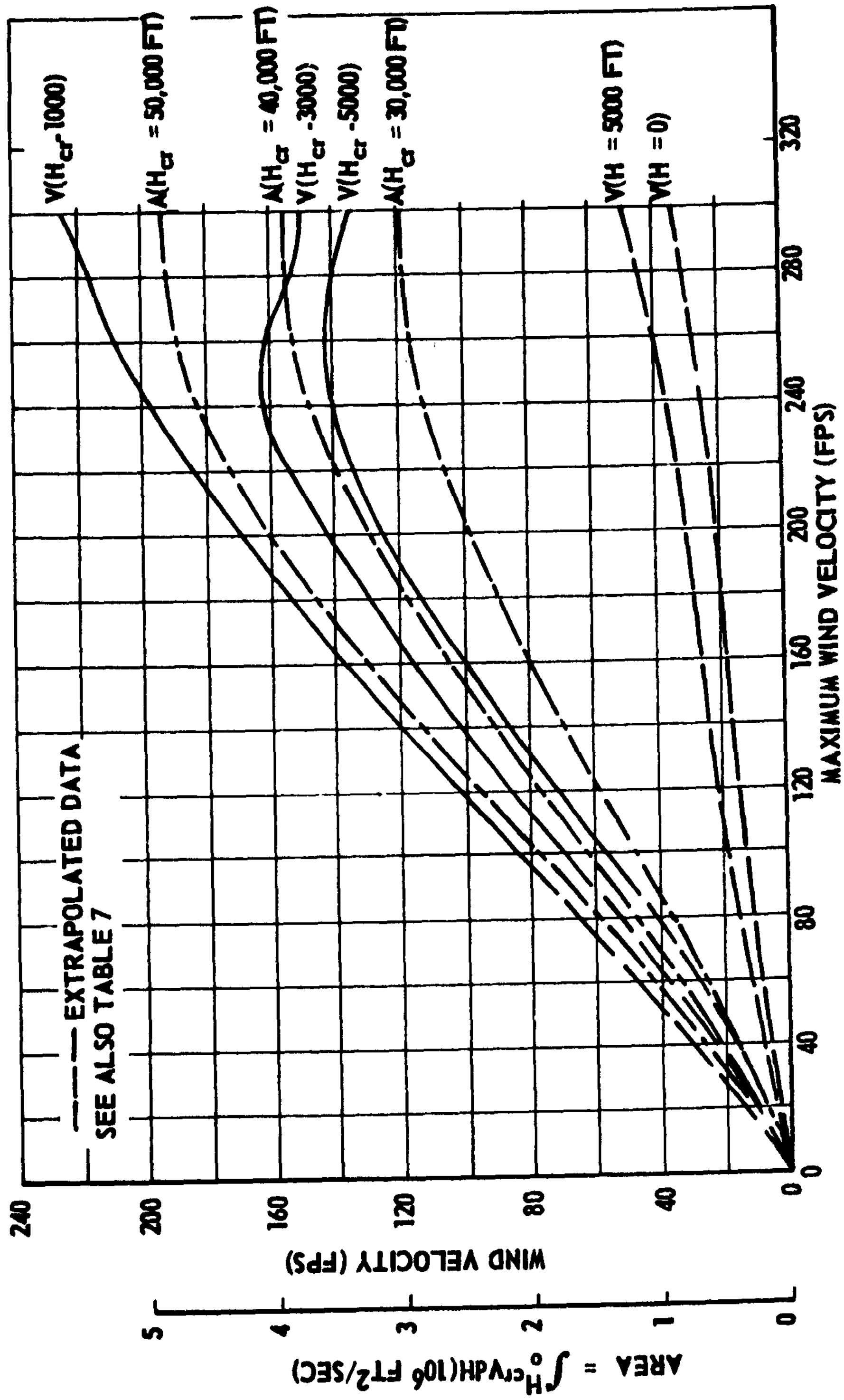


Figure 27 Parameters For Design Wind Profiles D3 and D4